PROBLEMS OF NEUROSURGERY
NAMED AFTER N.N. BURDENKO

№4 • 2015 • vol. 79
Founded in 1937.
Burdenko Neurosurgical Institute, Moscow, Russia

«Zhurnal voprosy neirokhirurgii imeni N N Burdenko» (Problems of Neurosurgery named after N.N. Burdenko) is a bimonthly peer-reviewed medical journal published by MEDIA SPHERA Publishing Group. Founded in 1937.

Journal is indexed in RSCI (Russian Science Citation Index), PubMed/Medline, Index Medicus, Scopus/EMBASE, Chemical Abstracts, Ulrich’s Periodicals Directory, Google Scholar.

MEDIA SPHERA Publishing Group:
Dmitrovskoe sh. 46-2, Moscow, 127238 Russia
Tel. +7 (495) 482 4329
Fax: +7 (495) 482 4312
E-mail: info@mediasphera.ru
www.mediasphera.ru

Correspondence address:
Moscow, P.O. Box 54, 127238 Russia
Advertising department: +7 (495) 482 0604
E-mail: reklama@mediasphera.ru
Subscription department: +7 (495) 482 5336
E-mail: zakaz@mediasphera.ru

Address of the editorial office:
4-ya Tverskaya-Yamskaya ul., 16, Moscow, 125047 Russia
Burdenko Neurosurgical Institute
Tel. +7 (499) 972 8566
E-mail: Vopr@nsi.ru
Managing Editor
V.K. Ivannikova
E-mail: VlIvannikova@nsi.ru

Art and Layout: MEDIA SPHERA Publishing Group

FREE FULL-TEXT ENGLISH VERSION
www.mediasphera.ru/journals/burdenko_en/index_en.html

The Editorial Board is not responsible for the content of advertising materials. Editorial opinion does not always coincide with the opinion of the authors. Only the articles prepared in compliance with Authors’ guidelines are accepted for publication. When submitting an article to the Editorial Board, the authors accept the terms and conditions of the public offer agreement. Authors’ guidelines and the public offer agreement can be found on website www.mediasphera.ru. Complete or partial reproduction is allowed by written permission of the Publisher (MEDIA SPHERA Publishing Group).
CONTENTS

ORIGINAL ARTICLES

Shekhtman O.D., Maryashev S.A., Yakovlev S.B., Golanov A.V., Shishkina L.V., Pilipenko Yu.V.,
Combined Treatment of Cerebral Arteriovenous Malformations. Experience of the Burdenko Neurosurgical Institute ................. 3

Endovascular Treatment of Large and Giant Intracranial Aneurysms Using Flow-Diverting Stents .................................................. 17

Endovascular Treatment of Large and Giant Intracranial Aneurysms Using Stent Assistance ............................................................ 25

Konовалов A.N., Pitskhelauri D.I., Melikyan A.G., Shishkina L.V., Serova N.K., Pronin I.N., Eliseeva N.M.,
Shkatova A.M., Samborskiy D.Ya., Bykanov A.E., Golovteev A.L., Grinenko O.A., Kopachev D.N.
Supracerebellar Transtentorial Approach to Tumors of the Posterior Mediobasal Temporal Region ....................................................... 34

Bykanov A.E., Pitskhelauri D.I., Dobrovolskiy G.F., Shkarubo M.A.
Surgical Anatomy of the Insular Cortex. ................................................... 44

Kim S.A., Letyagin G.V., Danilin V.E., Sysoeva A.A., Rzaev D.A., Moysak G.I.
The Use of Frameless Navigation During Endoscopic Interventions in Children with Multilocular Hydrocephalus ................. 56

Pronin A.I., Fomichev D.V., Shariyov O.I., Fadeeva L.M., Kornienko V.N.
Spiral CT perfusion in the Diagnosis of Sellar and Parasellar Tumors ............................................................. 65

FOR PRACTICE

Shimanskiy V.N., Karnaukhov V.V., Shishkina L.V., Vinogradov E.V.
Successful Treatment of a Patient with Lhermitte-Duclos Disease (a Case Report and Literature Review) ........................................ 70

Hemostat-induced Granulomatous Inflammation in the Resected Brain Cavernoma Bed in a Child ............................. 76

Cherekaev V.A., Gol'bin D.A., Belov A.I., Radchenkov N.S., Lasunin N.V., Vinokurov A.G.
Orbitozygomatic Approaches to the Skull Base .................................................. 86

In accordance with the resolution of the Higher Attestation Commission of the Ministry of Education and Science of the
Russian Federation, the Problems of Neurosurgery named after N.N. Burdenko was included in the List of Leading Peer-
Reviewed Journals and Periodicals issued in the Russian Federation where the main results of Candidate and Doctor Theses
are recommended to be published.
Combined Treatment of Cerebral Arteriovenous Malformations. Experience of the Burdenko Neurosurgical Institute


Burdenko Neurosurgical Institute, Moscow, Russia

Objective. Despite the achievements of recent years, cerebral arteriovenous malformations (AVMs) remain a challenge to treatment. The objective of this study was to develop the recommendations for combined treatment of AVMs that is based on analysis of the available material and published data. Material and Methods. The study included 93 patients hospitalized at the Neurosurgical Institute for combined treatment of cerebral AVMs in 2010—2014. A group of combined surgery (resection of an AVM with preoperative embolization) consisted of 40 patients, and a group of combined radiotherapy (irradiation after partial embolization or partial resection of an AVM) included 53 patients. Thirty-six patients underwent radiosurgery, and 17 patients received stereotactic radiation therapy. Both groups were analyzed in terms of outcomes, complications, and follow-up results.

Results. In the group of combined surgery, according to the Glasgow Outcome Scale, good outcomes (score of 4 or 5) were achieved in 35 (87.5%) patients at discharge and in 27 (90%) patients during follow-up. Treatment outcomes, surgery duration, and the amount of blood loss were not significantly different from those in the control group. Complete AVM obliteration was achieved in 29 (80.6%) patients 3 years after radiosurgery and in 8 (47%) patients after stereotactic radiation therapy. In discussion, these findings are compared to the published data, and recommendations for AVM treatment are suggested.

Conclusion. The combined treatment of AVMs is an effective therapeutic approach for patients with complex AVMs (Spetzler—Martin grade III—IV AVMs). Successful treatment of AVMs requires careful planning and teamwork of vascular and endovascular neurosurgeons, radiologists, and neurologists.

Keywords: arteriovenous malformation, combined treatment, surgical treatment of AVM, preoperative embolization, radiosurgery, stereotactic radiation therapy.

List of abbreviations

AVM — arteriovenous malformation;
GOS — the Glasgow Outcome Scale;
H&E — hematoxylin and eosin staining;
MSCT/MRI — multislice computed tomography/magnetic resonance imaging;
NBCA — n-Butyl cyanoacrylate;
PCA — posterior cerebral artery;
PCF — posterior cranial fossa;
RS — radiosurgery;
SRT — stereotactic radiation therapy;
TBD — total boost dose.

Arteriovenous malformation (AVM) is a congenital malformation of blood vessels, which was first described by W. Hunter in 1764 [1]. The incidence of AVMs in the population is 1.34 per 100,000 with male:female ratio of 1.1:1 (males are slightly predominant) [2, 3]. About 50% of AVMs are manifested with intracranial hemorrhage followed by the development of persistent neurological deficit in 21—83% of patients. The risk of repetitive hemorrhage is 6—17%; mortality rate is 10—15% [4].

Every year, approximately 120 patients with cerebral AVMs are admitted for surgery to the Burdenko Neurosurgical Institute. The choice of treatment is often a subject for discussion with the allowance for changing views to AVM surgery and accumulation of data on radiosurgeries. Combined treatment of AVMs (two or more techniques used in the treatment) did not include system analysis for a long time, while the role of the latter is becoming increasingly significant. In this study, a team of specialists of the Burdenko Neurosurgical Institute presents both an analysis of the outcomes of combined treatment for patients with AVMs and the views on therapeutic approaches for the disease.

Material and Methods

The study included 93 patients admitted to the Burdenko Neurosurgical Institute for the combined...
treatment of cerebral AVMs in 2010—2014. Retrospective analysis included 40 patients of “surgical” group who underwent embolization and resection of an AVM and 53 patients of “irradiation” group who underwent stereotactic radiation therapy (SRT) after either partial embolization or subtotal resection of an AVM.

1. AVM resection combined with preoperative embolization

The group included 40 patients with AVMs of the cerebral hemispheres or the posterior cranial fossa (PCF). The mean age of patients was 32.1±12.9 years. Male:female ratio was 26:17. Treatment outcomes in this group were compared to those of the control group to evaluate the effectiveness of preoperative embolization and its impact on treatment outcomes, intraoperative blood loss, surgery duration, time of stay at hospital, and other side effects of treatment. The control group was selected randomly among patients with AVMs who were operated on in 2010—2013 but did not undergo preoperative embolization. No statistically significant changes in the number of patients, age, sex, and clinical manifestations of the disease were revealed in the control group as compared to the study group (p<0.05). AVMs were preoperatively evaluated using the Spetzler-Martin AVM grading system with the allowance for the state of the critical regions of the brain: language zone, visual cortex, sensorimotor area, the area of the internal capsule, subcortical nuclei, and deep cerebellar nuclei.

More data on the study and control groups are presented in Table 1.

Distribution of AVMs in the study and control groups with respect to localization is presented in Table 2.

The study group included both patients who underwent AVM embolization and resection at the Burdenko Neurosurgical Institute within one day (33 patients) and patients with partially embolized AVMs who were admitted for AMV resection from other hospitals (7). The preoperative embolization was aimed at occlusion of difficult-to-access and deep-seated afferents of AVMs and hemodynamic aneurysms.

The degree of AVM embolization was evaluated based on angiograms in two projections according to the extent of contrasted areas and the rate of blood bypass in a malformation as a percent of the basic data. Functional treatment outcomes were evaluated on the Glasgow Outcome Scale (GOS). The follow-up data were obtained during control examinations of patients in the department or via a telephone interview. The duration of AVM resection, intraoperative blood loss, time of stay at hospital (including the time at the intensive care unit), as well as costs for each type of treatment were analyzed to assess the effectiveness of AVM embolization. Performance work and social rehabilitation of patients were also analyzed during follow-up examinations.

Outcomes of AVM resection combined with preoperative embolization

Thirty-nine (97.5%) out of 40 patients underwent embolization and resection of an AVM; one patient died due to complications after endovascular surgery. AVM embolization was performed using microcoils (9 patients), Histoacryl (8), microemboli (2), NBCA (15), and Onyx (3); combinations of the aforementioned embolic agents were used for 3 patients. Three patients with an aneurysm in the posterior inferior cerebellar artery and 1 patient with an aneurysm in the posterior cerebral artery (PCA) underwent microcoil endovascular occlusion of a hemodynamic aneurysm. Preoperative embolization was performed at 20—90% of the initial AVM volume. More than 50% of the AVM nidus was occluded in 29 (72.5%) patients; of them, 5 patients (12.5%) underwent subtotal embolization (Fig. 1).

In the total of 39 patients, AVM were successfully resected via microsurgery. In the early postoperative period, complete AVM resection during the combined treatment was confirmed for 23 patients based on the selective angiography data and for 3 patients based on the MSCT angiography data; the completeness of AMV resection for other patients was confirmed on the basis of the MSCT/MR angiography data in the late postoperative period.

Good outcomes (GOS score of 4 or 5) were obtained in 35 (87.5%) out of 39 patients in the group of combined treatment and in 37 (92.5%) patients of the control group. Poor outcomes (GOS score of 3) were detected in 3 patients after combined treatment and in 2 patients of the control group. One patient died in each group. In the study group, the patient died due to migration of a glue into the draining vein and superior sagittal sinus, which was followed by the development of diffuse edema and brain herniation. In the control group, the patient with an AVM in the PCF died due to massive air embolism. No statistically significant changes were observed in the treatment outcomes of both the study and control groups (U-test, p>0.05).

Long-term outcomes were assessed in 30 (75%) out of 39 operated on patients. The mean follow-up period was 27.6 months. According to the follow-up data, good treatment outcomes (GOS score of 4 or 5) were achieved in 27 (90%) patients; one patient remained severely disabled (GOS score of 3). Two patients died due to causes not related to their surgeries. Functional treatment outcomes of the study and control groups on the GOS scale are summarized in Table 3.

The average length of stay at hospital and in the intensive care unit of patients who underwent combined treatment was slightly longer compared to the control group. This fact can be explained by multistage surgeries requiring teamwork of two surgical teams and by postoperative monitoring of a number of parameters for
Table 1. Characteristics of the study and control groups

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Study group (embolization + resection)</th>
<th>Control group (resection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age of patients (σ), years</td>
<td>32.1±12.9</td>
<td>30.47±11.1</td>
</tr>
<tr>
<td>Male:female ratio</td>
<td>24:16</td>
<td>25:15</td>
</tr>
<tr>
<td>Critical region</td>
<td>26</td>
<td>23</td>
</tr>
<tr>
<td>Hemorrhage in past medical history, number of patients</td>
<td>23</td>
<td>27</td>
</tr>
<tr>
<td>Spetzler-Martin AVM grading system, number of patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>II</td>
<td>17</td>
<td>28</td>
</tr>
<tr>
<td>III</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>IV</td>
<td>3</td>
<td>–</td>
</tr>
<tr>
<td>V</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of the study and control groups with regard to AVM localization

<table>
<thead>
<tr>
<th>Localization</th>
<th>Study group (embolization + resection)</th>
<th>Control group (resection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temporal lobe</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Temporo-occipital region</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Occipital lobe</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>Frontal lobe</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Parietal lobe</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Parieto-occipital region</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>PCF</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</table>

preventing the syndrome of hyperperfusion and other complications.

No statistically significant changes were observed in the study and control groups regarding mean time of surgery and blood loss exceeding normal values of 500 mL (U-test, p>0.05).

Preoperative embolization required on average RUR 247,859; direct microsurgical intervention costed RUR 150,000—195,000, depending on the complexity of surgical procedures. Combined treatment required on average RUR 403,484. (All these prices are valid for October, 2014).

Duration of surgery, costs, and abnormal (regarding mean values) blood loss during the treatment are summarized in Table 4.

Case report 1

A 22-year-old male patient B. presented with the diagnosis of an AVM in the left cerebellar hemisphere. The patient underwent 17 Onyx glue embolization of the difficult-to-access pole of the AVM, which was followed by AVM resection.

Three months after the treatment, the patient was examined after severe intraparenchymal hemorrhage with fourth ventricle occlusion. Angiography data revealed an AVM in the left cerebellar hemisphere, which was feeding generally from hypertrophied anterior inferior and posterior inferior cerebellar arteries on the left. Blood outflow followed the convoluted drainage vein towards the confluence of sinuses. Considering the blood supply of the AVM from a difficult-to-access afferent vessel of the anterior inferior cerebellar artery circulation, Onyx partial embolization of the oral region of the AVM nidus was the first stage of the surgery: about 50% of the initial contrasted volume of the malformation was occluded. The AVM was completely resected during the subsequent direct surgery. The border zone of the embolized malformation was well differentiated from brain tissue, and AVM resection through the perifocal area was followed by a slight hemorrhage. The postoperative period proceeded relatively well, and the patient was discharged in satisfactory condition with the absence of neurological deficit (Fig. 2).

Case report 2

A 36-years-old male patient G. was admitted with a diagnosis of an AVM in the left parietal parasagittal region. The patient underwent partial embolization using Histoacryl and resection of the AVM.

Three times the patient suffered hemorrhage from the AVM of parietal region on the left (the central gyrus region). The patient underwent two times AVM embolization using Histoacryl at the place of residence. He suffered from partial epileptic seizures in the form of tonic seizures in his right upper limb, sometimes from generalized seizures. Neurological status at admission revealed the absence of focal neurological symptoms. Angiography data revealed the contrasted area of an AVM in the parietal parasagittal region that reached 30% of the original volume (Fig. 3a—d).

AVM resection through the perifocal area was almost bloodless. Vessels embolized by Histoacryl were grayish-
colored and had dense structure and areas in the border zone of the AVM with continued blood flow; these vessels were occluded with difficulty. As an outcome of the surgery, the AVM was resected completely, which was confirmed by angiography (see Fig. 3e). Microscopy revealed a mass of Histoacryl visualized in the vessel lumen and perivascular lymphocytic infiltrate in the vessel wall, which were caused by embolization (see Fig. 3f).

The patient was discharged with the absence of neurological deficit. No epileptic seizures were observed during the 2-year follow-up. The patient works and is completely socially adapted.

II. Stereotactic irradiation after AVM embolization or incomplete AVM resection

The group included 53 patients with cerebral AVMs, who underwent stereotactic irradiation after surgery or embolization in 2010—2011. Prior to scheduling radiation therapy, patients were counseled by vascular neurosurgeons: no surgical treatment was indicated for...
all candidates. The inclusion criterion in the study was the 3-year follow-up after irradiation and the outcome of radiation therapy confirmed with the MR/CT angiography data. Radiosurgery (RS) included stereotactic irradiation of a target in a single fraction and SRT in 2—5 fractions with target variables (Table 5).

Forty-three patients after partial endovascular embolization of an AVM, 8 patients after incomplete AVM resection, and 2 patients after endovascular and microsurgical treatment were subjected to stereotactic radiotherapy. A detailed description of the study group and the distribution of patients according to the Spetzler-Martin AVM grading system and clinical manifestations of the disease are presented in Table 6.

In terms of surgery, patients subjected to stereotactic irradiation were referred as a complex group of high risk. In almost half of all patients (25 patients, 47.2%), an AVM was referred as the Spetzler-Martin grade III malformation; in 19 (35%) patients, an AVM was referred as grade IV—V. The majority of patients (41 cases) had previously experienced hemorrhage from an AVM, 9 patients had suffered from epileptic seizures, and an AVM had manifested with headaches and other pseudotumor symptoms in 3 patients (see Table 6). More than half of the study population (32 patients) included patients with hemispheric AVMs. Thirteen patients with deep-seated subcortical AVMs, 2 patients with intraventricular AVMs, and 3 patients with an AVM of a hemisphere or of the cerebellar vermis were irradiated. Distribution of patients with regard to AVM localization is presented in Table 7.

Eight patients underwent SRT using the CyberKnife and 9 patients using the Novalis device. Both groups were subjected to irradiation in the hypofractionated regimen with the total boost dose (TBD) of 24—27 Gy on the CyberKnife (2 fractions) or TBD of 35 Gy on the Novalis (5 fractions), respectively.

The dose of irradiation depended on the location and extent of an AVM, estimated radioreactions, preexisting neurological deficit, and the fact of hemorrhage in the past medical history. Depending on the system used for irradiation, the isodose level typically ranged from 50 to 70% in the case of Gamma Knife irradiation and from 75 to 95% in the case of irradiation using linear electron accelerators. As the medication assistance, all patients received a single dose of dexamethasone (8 mg) at the end of radiosurgical procedure. Administration of other medications (e.g., anticonvulsants, cardiac medications, painkillers, etc.) continued.

For radioreaction assessment after SRT, the patients underwent MRI of the brain after 6 months and then after 1 and 2 years, depending on the severity of radiation-induced edema, radiation necrosis, and other
Complications. Obliteration of an AVM was evaluated based on the selective angiography and MR/MSCT angiography data 3 years after irradiation. The results of control examinations were studied by a council of three specialists (radiation therapist, radiologist, and neurosurgeon). In the case of doubtful or incomplete data, the patients were subjected to control selective angiography. If functioning fragments of an AVM were detected after 3 years, the patients were recommended to undergo repeated SRT. In the case of a significant decrease in the AVM volume (more than 70%) after 3 years and no hemorrhage in the latent period, the patients were recommended to undergo repeated angiography after 2 years.

Performance status of patients after radiation therapy was evaluated on the Karnofsky scale.

II. The outcomes of radiation therapy for AVM after embolization or incomplete resection

Radiosurgery. The mean follow-up period was 3.14±0.61 years. The mean volume of irradiated AVM was 12.24 (range of 8—36) cm³. The outcomes of radiosurgical irradiation were confirmed according to the selective angiography data in 19 (36%) patients and MSCT/MR angiography in 34 (64%) patients.

Complete AVM obliteration after radiosurgical treatment was achieved in 29 (80.6%) patients (i.e., in 9 patients after Gamma Knife irradiation, in 15 patients after the Novalis, and in 7 patients after CyberKnife treatment). RS caused partial obliteration of an AVM in 4 (11%) patients and proved to be ineffective in 3 patients. The outcomes of RS are summarized in detail in Table 8.

Symptomatic radiation-induced responses (edema accompanied by neurological symptoms), radiation necrosis, and cysts were observed in 1 or 2 (11—14%) patients who underwent different types of irradiation. Repetitive hemorrhage during the 3-year period of follow-up occurred in 1 patient after irradiation using the Gamma Knife and in 1 patient with a large AVM after Novalis treatment. As a result, 1 patient died from a hemorrhage. Thus, the overall mortality rate was 1.8%. The positive effect on the epilepsy syndrome (reduction

*Table 5. Distribution of patients with regard to the type of radiation therapy*

<table>
<thead>
<tr>
<th>Type of treatment</th>
<th>Novalis</th>
<th>CyberKnife</th>
<th>Gamma Knife</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiosurgery</td>
<td>18</td>
<td>7</td>
<td>11</td>
<td>36</td>
</tr>
<tr>
<td>Stereotactic radiation therapy</td>
<td>9</td>
<td>8</td>
<td>—</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>15</td>
<td>11</td>
<td>53</td>
</tr>
</tbody>
</table>
in seizure frequency, reduced doses of anticonvulsants, and changes in the severity of attacks towards milder episodes) was detected in half of the patients in each subgroup. Improved performance status on the Karnofsky scale was observed in approximately one-third of the patients, regardless of the device used, which was likely associated rather with the natural recovery of neurological function after hemorrhage than with the specific impact of irradiation. Due to a small patient selection, it was not possible to achieve a statistically significant data on the role of radiation therapy in terms of functional outcomes and epilepsy syndrome.

**Stereotactic radiation therapy.** SRT outcomes in 17 patients with confirmed 3-year-follow-up data are presented in Table 9. A small number of patients in the groups did not allow us to carry out valid statistical processing of the data. However, it was clear that the efficacy of SRT was lower (~50%) compared to the outcomes of AVM obliteration, and complication rates were higher than those of RS.

**Case report 3**

A 32-year-old female patient Sh. was admitted with the diagnosis of an AVM in the left occipital lobe. The treatment included Histoacryl embolization (2005), Onyx embolization (2006), RS using Novalis (2008), and AVM resection (2011).

Past medical history of the patient revealed that she had suffered from headaches for a long time and the attacks became more frequent after childbirth. An AVM in the left occipital lobe was detected based on MRI. According to angiography data, the AVM received blood supply from the branches of the left posterior and medial cerebral arteries; the blood was drained into the left transverse sinus (Fig. 4a, b). During two endovascular surgeries in 2005 and 2006, the AVM was embolized approximately on two thirds of the contrasted volume (see Fig. 4c). In 2008, due to recanalization of the malformation, AVM embolization using Onyx was performed (see Fig. 4d); the patient refused proposed AVM resection. It was decided to irradiate the residual portion of the malformation using the Novalis system. The target volume was 1.47 cm³; the isocenter dose of 26 Gy was delivered with 80% isodose (see Fig. 4e). However, a contrasted area of a small residual portion of the AVM was still detected during control angiography after 2.5 years. The AVM was successfully resected, which was confirmed with the MSCT angiography data after 1 year. The patient was neurologically preserved except visual field defects (complete right-sided hemianopsia).

**Case report 4**

A 31-year-old male patient A. was admitted with the diagnosis of an AVM in the right temporal lobe. The treatment included clipping of afferent vessels (1997), proton therapy (2000), embolization using TRUFILL microcoils (2004), and RS with the Novalis device (2008).

As a child, the patient experienced two times severe parenchymal hemorrhage from the AVM in the right temporal lobe; both times the patient underwent emergency surgery at the place of residence. During reoperation in 1997, AVM afferents from the right medial cerebral artery were clipped after hematoma resection. In 2000, proton therapy was performed with no evidence of a positive effect: the AVM continued to receive blood supply from the branches of the left medial cerebral artery and meningeal branches of the external carotid artery (Fig. 5a). At the Burdenko Neurosurgical Institute, endovascular AVM management using TRUFILL microcoils was performed in 2004, and the residual portion of the AVM was irradiated using the Novalis system in 2008. The target volume was 1.47 cm³; the isocenter dose of 26 Gy was delivered with 80% isodose.
Control selective angiography after 6 years revealed the absence of contrasted AVM mass. No focal neurological symptoms were detected.

**Discussion**

In terms of surgical treatment and its risks, patients with cerebral AVMs are a sufficiently diverse group. The Spetzler-Martin AVM grading system (1986) has proven particularly useful to assess the risk of AVM treatment. This scale still remains the most accurate integrated scale for predicting the outcomes of surgical treatment. For instance, the surgery of grade I—III AVMs is being at moderate risk, while grade IV—V AVMs involve high risk of postoperative complications and mortality. The therapeutic approach for grade I—II AVMs is generally doubtless, but grade III—IV AVMs (which are large in size, have deep-seated afferents, the presence of drainage, and often involve the critical regions of the brain) are a complex subject for treatment.

Our study demonstrated that preoperative embolization of the portions of a malformation that are difficult to access and deep-seated afferents enables switching an AVM to the group at lower risk without impairing treatment outcomes. For example, 21 patients with Spetzler-Martin grade III—IV AVMs were operated on in the study group, while only 4 patients of the same grade underwent surgery in the control group; good treatment outcomes (early and delayed) were achieved in both groups.

The role of endovascular treatment of AVMs has somewhat changed in recent years. The literature analysis shows that total occlusion can be achieved in 16—32.8% of cases; however, some authors who are using Onyx give higher rates of total AVM embolization (51%). According to I. Saatci et al. [5], the risks of endovascular embolization of AVMs (2—8.7%) and mortality rate (0.8—3%) are sufficiently low (see Table 8).

It should be noted that the reliability of endovascular treatment is lower compared to microsurgical treatment. This is due to delayed recanalization of a malformation and opening of new perinidal vessels around the nidus, which is detected in 15—20% of cases (J. Mathis et al. [11]). Histoacryl embolization of AVMs shows signs of recanalization within 6—12 months. As a primary treatment, AVM embolization is justified for small lobar AVMs with afferents easily accessible for cannulation and with the best prospect of complete embolization. In other cases, endovascular treatment should be regarded as a supplementary option but not as an independent treatment mode for AVMs.

The role of embolization of an AVM before resection and RS is slightly different with respect to the purposes of preoperative preparation:

1. cutting off deep-seated inaccessible for direct surgery afferents from circulation of the choroidal arteries, from PCA, and from perforating arteries;
2. decreased volume of the functioning nidus;
3. decreased rate of shunting of blood in an AVM;
4. occlusion of hemodynamic aneurysms.

When performing preoperative AVM embolization, the specialists of the Burdenko Neurosurgical Institute follow the established surgical principles:

1. High-flux AVM afferents should be occluded with microcoils, since the use of a glue bears the risk of distal migration of a glue followed by drainage occlusion of an AVM and sinus occlusion.
2. Obliteration of AVM stroma is not an absolute goal. Embolization of the afferents that are difficult to be accessed in the subsequent open surgery or are the main arteries feeding an AVM seems to be more effective.

3. AVM embolization and resection should be performed within one day, thus minimizing the risk of hemorrhage and edema due to restructuring of blood circulation in the AVM.

4. AVM embolization is a technically complex procedure that must be performed by an experienced team of endovascular surgeons using proven techniques and embolic agents.

Radiation-induced AVM obliteration is based on active endothelial cell proliferation in the walls of blood vessels that is associated with increased myofibroblast activity [12]. Radiosurgical treatment is highly effective in the case of small size AVMs, while irradiation of malformations that are more than 15 cm³ require multistage treatment or hypofractionated regimen, when the TBD is delivered in a minimum number of fractions at highest doses per fraction. S. Sirin et al. [13] demonstrated that multistage RS result in the best outcomes, allowing the healthy brain tissue to recover between stages of treatment.

The obliteration process is lengthy. Although the first signs of AVM obliteration are detected in patients after 2—3 months according to G. Szeifert et al. [12], complete AVM obliteration is detected in only 50% of patients by the end of the first year of follow-up. After RS, it is achieved in 80% of patients within 2 years and in 90% within 3 years. In our series of cases, the rate of complete AVM obliteration during 3-year follow-up has reached 80.6%, which is a relatively high level.

The risk of radiation-induced complications (in particular, repetitive hemorrhage from an AVM during a latent period after RS) is comparable to the natural course of the disease. As H. Kano et al. showed in a recent study [14], the average risk of hemorrhage in patients 3 years after RS was 5.5%. According to the meta-analysis of H. Kim et al. [15], the rate of repetitive hemorrhage was 4.8% in patients with an AVM who were under follow-up. In our study, a single case of repetitive hemorrhage after irradiation using the Novalis device was detected (5.5%). As previously showed S. Maryashev et al. [16], risk factors for repetitive hemorrhage after RS include hemorrhage in past medical history and a single draining vein.

Presurgical embolization of an AVM significantly prolongs the latency period and adversely affects the
completeness of obliteration of a malformation [17, 18]. In our view, endovascular treatment of AVMs before irradiation is indicated for hemodynamic aneurysm embolization or partial resection of a functioning part of large multiple AVMs when the size of the nidus requires multistaged fractionated irradiation.

Other causes of incomplete AVM obliteration after RS may be as follows: incorrect assessment of limits/size of an AVM, the lack of necessary 3D-image of a nidus, insufficient dose to achieve obliteration, compression of an AVM with hematoma during irradiation in the subacute stage of hemorrhage, etc. [19].

The group of patients who are considered difficult to treat is presented by cases of large symptomatic AVMs with multichannel blood supply that were located in the critical regions of the brain. The risk of repetitive hemorrhage or progressive symptoms (e.g., epilepsy syndrome) justifies the active treatment strategy but the location and size of a malformation allow for only palliative care. In such cases, endovascular treatment, as indicated above, should be aimed at embolization of hemodynamic aneurysms and large afferents to reduce the blood shunting rate. Partial embolization may have a positive therapeutic effect in patients with refractory epilepsy syndrome or progressive neurological deficit due to reducing venous hypertension or due to steal syndrome. However, palliative embolization of inoperable malformations should be indicated strictly on the individual basis, since it does not reduce the risk of repetitive hemorrhage and does not improve treatment outcomes, as showed O. Kwon et al. [20] and X. Lv et al. [21]. Palliative embolization, in our view, can be considered as a stage of treatment that is prior to SRT and it should be indicated strictly on the individual basis.

Fig. 5. Patient A., 31 years of age. AVM in the right temporal lobe.
a — right-sided carotid angiography reveals an AVM in the right temporal region that is feeding from branches of the right medial cerebral artery and meningeal branches of the external carotid artery; b, c — plan of RS using the Novalis system; d, e — control carotid angiography shows no filling of the AVM.
### Table 10. Outcomes of AVM embolization in the largest series of patients

<table>
<thead>
<tr>
<th>Author, year of publication</th>
<th>Number of patients in the series</th>
<th>Persistent deficit, %</th>
<th>Mortality, %</th>
<th>Glue</th>
<th>Complete occlusion, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. Meisel et al., 2002 [6]</td>
<td>450</td>
<td>2.0</td>
<td>1.1</td>
<td>NBCA</td>
<td>16</td>
</tr>
<tr>
<td>C. Taylor et al., 2004 [7]</td>
<td>201</td>
<td>9</td>
<td>2</td>
<td>NBCA</td>
<td>–</td>
</tr>
<tr>
<td>D. Sahlein et al., 2012 [8]</td>
<td>130</td>
<td>6.2</td>
<td>0.8</td>
<td>NBCA</td>
<td>32.8</td>
</tr>
<tr>
<td>V. Katsaridis et al., 2008 [9]</td>
<td>101</td>
<td>8</td>
<td>3</td>
<td>Onyx</td>
<td>27.7</td>
</tr>
<tr>
<td>I. Saatci et al., 2011 [5]</td>
<td>350</td>
<td>7.1</td>
<td>1.4</td>
<td>Onyx</td>
<td>51</td>
</tr>
<tr>
<td>Yakovlev et al., 2012 [10]</td>
<td>723</td>
<td>4.3</td>
<td>1.3</td>
<td>NBCA/Onyx</td>
<td>30.5</td>
</tr>
</tbody>
</table>

### Fig. 6. Algorithm of the choice of therapy for ruptured cerebral AVMs.
The risk of RS-induced complications depends upon marginal dose and irradiated volume and does not depend upon the location of an AVM. J. Flickinger et al. specified that radiation-induced changes on the MRI of the brain are identified in approximately 30% of cases in the first 24 months after irradiation. Two third of these patients had edema visualized around the AVM nidus, but this reaction was accompanied by clinical symptoms in only 10% of cases. Corticosteroids for several weeks and the 3-month Trental and vitamin E administration are indicated as a medical assistance for patients with symptomatic radiation-induced edema [22—24].

According to R. Starke et al. [25—28], late (delayed) RS-induced complications include: cysts (1.5%), delayed hemorrhage (0.07%), radiation-induced chronic edema (0.08%), radiation necrosis (0.09%), and radiation-induced tumors (0.02%). The incidence of these complications is low; however, they require surgical treatment in some cases, which confirms the need for a delayed follow-up in patients who underwent RS.

**Guidelines**

Microsurgical treatment is scheduled for all patients with symptomatic AVMs (grade I—III according to the Spetzler–Martin AVM grading system). In the acute period, surgeries are performed for health reasons and include palliative care (intracerebral hematoma resection, decompressive craniotomy, etc.); AVM resection should be avoided if possible.

Combined surgery should be considered in patients with Spetzler–Martin grade III—IV AVMs. In these cases, indications are determined individually on the basis of the age, clinical presentation, localization, and prospects of AVM embolization.

Preoperative embolization as the first stage of the combined treatment is indicated for deep-seated AVMs with afferents that are difficult to be accessed, as well as for cutting off the blood supply from large vessels to reduce the blood flow before resection. AVM embolization and resection should be performed within one surgical day to minimize the risk of hemorrhage and recanalization of an AVM.

Endovascular occlusion of hemodynamic aneurysms is indicated for all patients prior to AVM resection or radiation therapy.

Endovascular embolization as an isolated therapy should be considered only in patients with minor Spetzler–Martin grade III malformations with a high probability of total AVM occlusion.

Radiosurgery is indicated for patients with an AVM of less than 15 cm³ when surgical treatment is not indicated due to localization of an AVM, severe condition of the patient, etc. Patients with AVMs more than 15 cm³ in size are recommended to undergo RS in the hypofractionated regimen. Preoperative embolization before irradiation should be referred as inappropriate, and one should perform it only for palliative care of large AVMs.

Patients with large (more than 6 cm³), deep-seated, and anatomically complex AVMs with high surgical risk require RS. This therapy should be also considered for somatically preoccupied and severely disabled patients (e.g., after repetitive hemorrhages). Preoperative embolization in such cases is justified for hemodynamic aneurysm occlusion, reducing the rate of blood shunting, and for partial occlusion of an AVM (e.g., bleeding site of a malformation). The algorithm of the choice of therapeutic approach for patients with symptomatic AVMs that is used at the Burdenko Neurosurgical Institute is presented in Fig. 6.

**Conclusion**

The treatment of AVMs remains a challenge to vascular neurosurgery that requires a teamwork of specialists, including vascular and endovascular neurosurgeons, radiologists, neurologists, and anesthesiologists. The decision on the treatment tactics for patients with cerebral AVMs should be determined on the individual basis in each case with regard to clinical experience and available technical capabilities.

**REFERENCES**


decades has greatly progressed, mainly towards the development successfully managing patients with vascular diseases. It should with AVMs (about 120 patients a year) among those who are there is a sufficiently large number of hospitalized patients challenges for vascular neurosurgeons. As the authors noted, tions (AVMs) remains one of the most significant and difficult 16.

Both microneurosurgery and endovascular neurosurgery departments of the Burdenko Neurosurgical Institute are successfully managing patients with vascular diseases. It should be noted that treatment of cerebral AVMs for the past two decades has greatly progressed, mainly towards the development of endovascular techniques. The emergence of new microcatheters, glues (Onyx and NBCA), and serigraphy with the capability of 3D imaging significantly strengthened capacities of surgery, enabling complex treatment for patients with previously inoperable malformations. At the same time, with accumulation of data on endovascular interventions, as the authors indicated, it became apparent that utter rejection of open surgery is not inevitable. According to various literature sources, complete AVM embolization is just over 50% (depending on the study, glue used, etc.). Meanwhile, the effectiveness of partial embolization remains in question, as the number of authors (e.g., Miyamoto et al.) found that it causes effectiveness of partial embolization remains in question, as the open surgery is not inevitable. According to various literature

| Objective. | Surgical treatment of arteriovenous malformations (AVMs) remains one of the most significant and difficult challenges for vascular neurosurgeons. As the authors noted, there is a sufficiently large number of hospitalized patients with AVMs (about 120 patients a year) among those who are admitted to the Burdenko Neurosurgical Institute. Both microneurosurgery and endovascular neurosurgery departments of the Burdenko Neurosurgical Institute are successfully managing patients with vascular diseases. It should be noted that treatment of cerebral AVMs for the past two decades has greatly progressed, mainly towards the development of endovascular techniques. The emergence of new microcatheters, glues (Onyx and NBCA), and serigraphy with the capability of 3D imaging significantly strengthened capacities of surgery, enabling complex treatment for patients with previously inoperable malformations. At the same time, with accumulation of data on endovascular interventions, as the authors indicated, it became apparent that utter rejection of open surgery is not inevitable. According to various literature sources, complete AVM embolization is just over 50% (depending on the study, glue used, etc.). Meanwhile, the effectiveness of partial embolization remains in question, as the number of authors (e.g., Miyamoto et al.) found that it causes an increased risk of hemorrhage. |
In addition, the Department of Radiology of the Burdenko Neurosurgical Institute uses modern SRT systems (the Gamma Knife, Novalis, and CyberKnife devices) since 2009. Thus, the challenge posed by the authors to summarize the data on combined treatment for AVMs is of undoubted interest for specialists.

**Study.** The authors presented the modern outcomes of combined treatment of 93 patients with AVMs. The study was divided into two fields regarding patients who underwent microsurgical treatment after preoperative embolization of an AVM (40 patients) and patients (53 cases) who underwent SRT after embolization or incomplete resection of an AVM.

Both study groups were classified according to the standard Spetzler-Martin AVM grading system, as well as according to AVM localization, patients’ age, selected treatment strategy, and clinical manifestations of the disease.

The outcomes of the combined surgical treatment of patients at discharge and delayed outcomes were assessed on the Glasgow Outcome Scale and were compared to the control group. In most patients (72.5%), more than 50% of an AVM was occluded after preoperative embolization; embolization caused the migration of a glue into the sinus in 1 patient. Good treatment outcomes (GOS score of 4 or 5) were achieved in 35 (87.5%) operated on patients at discharge and in 90% of cases in the follow-up period. Treatment outcomes in the study group were comparable with those of the control group; the latter, however, included less complex cases in terms of surgery: in the study group, 21 (52%) patients had Spetzler-Martin grade III—IV AVMs, whereas there were only 4 (10%) patients with this grade of AVM in the control group. In selected cases, as the authors showed, embolization enabled to “transform” a more complex AVM into a milder form, without prejudice to treatment outcomes.

Interestingly, in the case of the time of inpatient care and the time of patients in the intensive care unit exceeded the terms expected in the control group, the authors failed to show the impact of embolization on the volume of blood loss during surgeries. The duration of resection of embolized AVMs was found to not differ from non-embolized AVMs in the control group.

The authors demonstrated clinical cases of AVMs in the left cerebellar hemisphere embolized with Onyx and AVMs in the parietal region that were embolized in a few stages using Histoacril. The cases are well illustrated and include data on microscopy of the biopsy material, but do not include intraoperative images, which obviously would have improved the study.

The group of combined radiation therapy included 53 patients who underwent either RS or radiotherapy with three different systems (the Gamma Knife, Novalis, and CyberKnife devices). The group included complex high-risk patients: 25 (47.2%) patients had Spetzler-Martin grade III AVMs and 19 (35%) patients had grade IV—V AVMs. The limit of follow-up was 3 years; the outcomes of radiation therapy in all patients were verified based on the data on selective angiography or MSCT angiography.

In each mode of irradiation, unfortunately, the number of patients was insufficient for statistical analysis and invalid to draw correct conclusions (see Table 5). It is worth noting that complete obliteration was obtained in 29 (80.6%) out of 36 patients who underwent RS. SRT performed in patients with large AVMs in the hypofractionated regimen (from 2 to 5 fractions) was less effective as expected: AVM obliteration was confirmed in half irradiated patients. In Table 8, the authors presented the outcomes and complications of radiation therapy; single cases revealed worsening of performance status. One patient died from repetitive hemorrhage after irradiation. Thus, the mortality rate was 1.8%.

In the “Discussion” section, the authors argue for a more cautious attitude toward AVM embolization as an independent method of treatment, which nevertheless has significant clinical relevance in certain cases. This section also presents the principles of preoperative AVM embolization with noted need for embolization of high-flux afferents, hemodynamic aneurysms, and difficult-to-access vessels, which helps the surgeon during the subsequent AVM resection.

The authors emphasize the need for limited selective AVM embolization for patients who were scheduled for RS, since the effectiveness of the latter is higher in the case of non-embolized AVMs. At the same time, AVM embolization plays a role in the palliative care of large and multiple malformations. A detailed analysis of the literature data and the validity of the algorithm of choice tactics for treatment of ruptured AVMs accepted in the Burdenko Neurosurgical Institute is an undoubted advantage of the study. Unfortunately, the algorithm does not include asymptomatic and unruptured AVMs.

*V.A. Lazarev (Moscow, Russia)
Large and giant (15 mm or more) cerebral arterial aneurysms account for 5—8% of all intracranial aneurysms. In this pathology, five-year risk of morbidity and mortality from rupture, ischemia or mass effect may be as high as 50% [1]. The vast majority of these aneurysms manifest as a mass effect on the surrounding brain structures and cranial nerves, causing progressing focal neurological symptoms. In almost every fourth patient the pathology manifests as spontaneous subarachnoid hemorrhage (SAH). In 5% of cases, the patients have ischemic disorders of cerebral circulation of thromboembolic origin.

Direct surgical treatment results in adverse outcomes in 1/3 of the patients. The results of surgical treatment of aneurysms in vertebrobasilar basin are significantly worse than those for carotid aneurysms [2—4]. Endovascular occlusion of aneurysm cavity with microcoils is not a method of choice, either, because in addition to high degree of recanalization, “induration” of aneurysms usually aggravates their impact on the surrounding tissues. Deconstructive operations (occlusion of aneurysm together with the parent vessel or proximal occlusion of the parent vessel) is feasible only for aneurysms located proximally to the circle of Willis or distal vessels aneurysms, and even then only if there is adequate collateral circulation in the occluded vessel basin. Some cases require arterial bypasses, but the risk of ischemic disorders in the postoperative period remains [5].

At the turn of the XXI century, the search for methods of isolating large and giant aneurysms while preserving the lumen of the parent vessel led to the creation of flow-diverting stents (FDSs) with small pores, which opened up new possibilities for treatment of the patients with this complex pathology. The mechanism of its action is to redirect the blood flow to the parent vessel, which creates the conditions for thrombosis of aneurysm cavity without the use of mircocoils. The FDS technique is relatively new, therefore there is a limited number publications devoted to it [6—10], and the causes of complications and long-term outcomes of such operations are insufficiently understood.

The objective of the study was to evaluate the efficacy of treatment of patients with large and giant cerebral arterial aneurysms using FDSs.

**Material and Methods**

A total of 210 patients (54 women and 156 men (1:2.7 ratio) aged between 12 to 77 years) with large and giant cerebral arterial aneurysms has been operated on between November 2009 and December 2014. The age distribution of the patients was as following: 10—20 years, 10 patients (all patients in the pediatric group were older than 12 years); 21—40 years, 49 patients; 41—60 years, 125 patients; over 60 years, 36 patients.

Clinical manifestations of the pathology are shown in Fig. 1. Asymptomatic aneurysms were detected incidentally, usually during examinations for unrelated conditions. Headaches experienced by the patients cannot always be linked to the aneurysm. The average period of aneurysm clinical manifestation from the onset of symptoms to the surgery was 40.2 months.

Primary diagnosis and indications for the surgery were based mainly on data from MRI, MR-angiography
and SCT-angiography. The data from direct contrast angiography were available in some cases.

A total of 70 (33%) patients had concomitant cerebral pathology; 40 of them underwent a series of surgical procedures unrelated to aneurysms and treated with FDSs (25 endovascular operations, 15 direct ones). Multiple aneurysms of different sizes and localizations and the brachiocephalic arteries lesions (constrictive and deforming in nature) were the most frequent.

Prior to the surgery all patients underwent endoscopy (esophagastroduodenoscopy) to exclude erosive and ulcerative lesions of the stomach and the duodenum. Dual antiplatelet therapy was prescribed in the absence of upper GI pathology or after appropriate treatment: 75 mg clopidogrel and 100 mg aspirin for 3—7 days. After successful implantation of the stent, the patients continued the therapy for 6 months after the surgery. The assessment of the effect of antiplatelet agents on platelet function prior to the surgery was performed on INNOVANCE PFA-200 aggregometer (“Siemens”) using collagen-epinephrine (screening), collagen-ADP (aspirin) and P2Y (clopidogrel) cartridges. The drugs were considered to be efficient and the surgery feasible if the aggregation time was longer than 300 s. If there were signs of resistance to clopidogrel, ticagrelor was prescribed at a dose of 180 mg/day. This scheme began to be applied in October 2012 and 96 patients have been treated since the time.

2D (DSA) and 3D angiography was used for detailed elucidation of anatomical parameters of the aneurysm (configuration and size of the aneurysm and its neck, relationship to the parent vessel and outgoing branches, and the state of the communicating arteries) and usually immediately preceded the surgery. In total, 255 aneurysms were verified in 210 patients, including 220 large and giant cerebral arterial aneurysms. 176 patients had single aneurysms, whereas 34 had multiple aneurysms.

A total of 214 out of 220 large and giant aneurysms were true and 6 were false. All false aneurysms were localized in the cavernous section of the internal carotid artery (ICA) and were formed after endovascular disconnection of the carotid–cavernous fistula. The share of giant aneurysms was 62.3% (137 cases). Six (2.7%) aneurysms were fusiform. Most aneurysms (85.5% (188 cases) were located in the carotid basin; 14.5% (32), in the vertebrobasilar basin (Fig. 2, 3). A total of 88 (42%) aneurysms contain clots.

Pipeline (EV3, USA) stents with a diameter of 3 to 5 mm and length of 14 to 35 mm were used to remodel the parent vessel. The stent was deployed through a microcatheter with an internal diameter of 0.027 inches (“Marksman”, EV3, USA). The surgery was completed by sealing the puncture site at the femoral artery by ExoSeal (“Cordis”, USA) and AngioSeal (“St. Jude Medical”, USA) 6F–8F vascular closure devices.

The long-term thrombosis of the aneurysm was assessed by SCT and MR-angiography or, in some cases, by direct contrast angiography 4 to 24 months after the surgery.

Results

Immediate results of the surgery

A total of 253 stents were implanted to treat 220 large and giant aneurysms in 210 patients. The number stents ranged from 1 to 5 per patient, depending on the number of aneurysms, length of the neck and technical failure of the initial implantation of the stent. The average number of stents per aneurysm was 1.14.

In 197 patients the surgery was single-stage, in 13, it consisted of two stages. Stent installation was performed in two stages in 4 patients with single aneurysms because it was impossible to catheterize the parent vessel distal of the aneurysm or due to inadequate positioning of the stent in the first stage. Eventually, successful implantation of the stent was achieved. The surgeries performed in two stages had an interval of 1 week to 3 months.

Technical results of the surgery

Stent implantation was successful in 211 cases (96% technical success rate). Of them, there were 22 cases of the stent dislocation with migration into the aneurysm or incomplete closure of its neck, which required installation of an additional stent (17 patients) or removal of the dislocated stent (5). Secure sealing of the aneurysm area and adequate remodeling of the arterial lumen required telescopic implantation of an additional stent in 18 cases. In-stent dilatation using balloons was performed in 48 cases due to incomplete expansion of the stent.

Additional coiling of the aneurysm cavity was performed in 9 cases: 4 cases of unintentional occlusion of the aneurysm or the parent artery due to technical failure during the installation of the stent and 5 cases of coils being installed into the cavity of the aneurysm in
advance to prevent its rupture. In 9 cases, the installation of the stent was unsuccessful for a number of reasons: unsuccessful attempts to catheterize the artery distal of the stent (2 cases), migration (dislocation) of the stent (5), failure to expand the stent (1), detachment of the delivery system (1). In 4 cases these failures resulted in forced occlusion of the parent vessel (3 cases) and spontaneous thrombosis of the artery (1). In two other cases, perforation of the arterial branch led to fatal hemorrhagic complications.

Hemodynamic changes (Fig. 3 and 4) were assessed by the control angiography immediately after the implantation of the stent in 192 patients (excluding 18 patients who underwent additional or prior occlusion of the aneurysm with coils, occlusion of the parent vessel or unsuccessful attempts to catheterize the artery).

Clinical results of the surgery

In the overwhelming majority of cases, neurological symptoms in the postoperative period remained stable (188 (90%) patients). Improvement of the clinical picture was observed in 3 patients (regression of oculomotor disorders due to alleviation of the mass effect).

Clinical complications developed in 12 (5.7%) patients: after 5 surgeries accompanied by technical complications and 7 technically successful surgeries. Three patients had transient ischemic attacks; in 9 patients the deterioration was associated with inadvertent occlusion/thrombosis of the parent artery. In 6 patients these complications resulted in ischemic disorders of cerebral circulation, whose outcomes ranged from mild (3) to pronounced (3) neurological deficit. Another 3 patients had pronounced headaches which regressed at the discharge following NSAIDs therapy.

Seven patients died in the early postoperative period from ischemic disorders of cerebral circulation in the vertebrobasilar basin (2) or hemorrhagic complications (5). In both cases ischemic disorders had been caused by in-stent thrombosis within 30—40 min after the surgery despite reaching target values of platelet aggregation. One of the patients had 5 telescopically implanted stents, while the other one had only 1 stent. In the latter case, the patient died despite extraction of the clot and thrombolytic therapy. The causes of hemorrhagic complications included perforation of the branch artery (middle cerebral and posterior cerebral arteries, 2 cases) and spontaneous rupture of the aneurysm 3—5 days after surgery (3 cases) (Fig. 5).

Therefore, 12 (5.7%) patients developed complications in the perioperative period with 6 of them
(2.8%) being clinically significant. Postoperative mortality was 3.3%.

**Long-term treatment outcomes**

**Long-term hemodynamic changes.** The long-term outcomes were followed up in 122 (58.1%) patients for 1 to 49 months after surgery. A total of 105 (86%) patients underwent control examinations: digital subtraction angiography (DSA, 25 patients), SCT-AG (64), MR-AG (14), SCT (2).

Hemodynamic changes in the long-term period are presented in Fig. 6. Complete occlusion of the aneurysm was observed in overwhelming majority of cases. In 6 (5.7%) cases aneurysms were thrombosed together with the stent (5 cases were asymptomatic and 1 experienced transient blindness).

In 2 cases, it was not possible to assess the degree of occlusion (CT was performed without contrast). It should be noted that thrombosis of the aneurysms occurred mainly at 6 months after the surgery and was observed for large and partially thrombosed giant aneurysms (Fig. 7). The involution of giant non-thrombosed aneurysms was observed at later date. A significant dislocation of the stent to the position proximal of the aneurysm neck was convincingly demonstrated in 2 cases when aneurysm continued to function fully at 6 months. In these cases an additional stent was implanted at the second stage, and complete thrombosis of the aneurysm was observed after another 6 months. In total, complete long-term occlusion was achieved in 80% (84 cases).

**Long-term clinical outcomes.** Complete regression of symptoms was observed in 32 (26.2%) patients; partial regression of symptoms, in 43 (35.2%); no response, in 38 (31.1%); deterioration, in 6 (4.9%). In 4 patients the deterioration was associated with the onset of ischemic disorders of blood circulation (with positive dynamics after conservative treatment). In 2 cases of supraclinoid localization of aneurysms, amaurosis was observed which can be attributed to disruption of blood circulation in the optic nerve due to progressing compression by thrombosing aneurysm. In one case a rupture of the
aneurysm in the cavernous segment of the ICA resulted in the formation of carotid-cavernous fistula 2 months after the operation with typical clinical presentation. Transvenous access was used to disconnect the fistula.

Three (2.5%) patients died, including 2 cases of sudden death from unknown causes at 1 and 4 months after the surgery (potentially associated with discontinuation of the antiplatelet therapy), and a death from the aneurysm rupture and massive subarachnoid intraventricular hemorrhage 1 month after surgery. These patients were not monitored for sensitivity to the antiplatelet therapy. Therefore, clinically significant long-term complications have been observed in 6 (4.9%) patients and the mortality amounted to 2.5%.

**Discussion**

The remodeling the parent vessel using FDSs is undoubtedly a revolutionary step in the treatment of aneurysms with complex configurations, such as large, giant and fusiform aneurysms, most of which were considered to be inoperable until recently.

The practical experience, reflected in publications over the past 3 years, testifies to the high efficiency of the method and good functional outcomes that will only improve with increased number of cases and continuous refinement of the design of the stent and delivery system. According to the literature, the technical success of the stent implantation is 90—99%, and in 50—95% of cases complete thrombosis of aneurysms occurs within 6 months. In the treatment of large and giant aneurysms this success rate is achieved through the unique design of stents: their semi-permeability can significantly alter the aneurysm hemodynamics immediately after the implantation, creating a zone of slow blood flow and even no blood flow in the aneurysm cavity, redirecting the flow to the parent vessel.

Postoperative morbidity and mortality vary significantly and range between 3—14% and 1—10%, respectively. However, they are significantly better than the corresponding rates for the natural course of the disease and direct surgery [2, 11—15]. In our series, postoperative disability amounted to 2.8%, and mortality was 3.8%; in the long-term they were 4.9 and 2.5%, respectively.

Despite the overall positive outcomes of the surgery, there are a number of unresolved issues related to the changes in hemodynamics. The most mysterious and poorly understood issue is such a serious complication as intracranial hemorrhage in the immediate and long-term periods after the surgery. Several authors [6] mention the initiation of aseptic inflammation in the aneurysm wall and adjacent tissues, leading to the development of necrotic changes in the aneurysm wall, which may cause its rupture. Typically, intracranial hemorrhages are fatal in these cases, since they occur in patients receiving antiplatelet drugs. In our opinion, this mechanism is more typical for delayed hemorrhages. To prevent such hemorrhages, I. Saatci et al. [14] recommend (most likely based on empirical data) hormonal therapy both intraoperatively and for 2 weeks after the surgery in conjunction with NSAIDs. However, it is still unclear how efficient this regimen is. Nevertheless, treatment outcomes of the patients in the series are among the best.

**Fig. 5. Rupture of aneurysm in the basilar artery 4 days after installation of FDS.**

a — angiogram of the left VA: visualization of a large aneurysm in the middle part of the basilar artery; b — sectioned material: a large surface of the aneurysm wall defect (arrow) with blots visualized in the cavity; c — microscopy of the aneurysm wall: marked damage to the aneurysm wall (arrows) and the presence of clot.

**Fig. 6. Changes in aneurysms hemodynamics.**
Aneurysm rupture in the immediate postoperative period may be caused by purely mechanical action of a rapidly forming blood clot on the thinned aneurysm wall [16, 17]. In all likelihood, in our series this mechanism of rupture is responsible for the deaths of 4 patients on 3—5th day (Fig. 5). Prevention of rapid formation of clots is directly related to the adequacy of the antiplatelet therapy. Therefore, the effectiveness of this therapy in patients should be verified preoperatively by laboratory methods. According to our data, low sensitivity to clopidogrel was observed in 18.5% of cases and required increasing the dose of the drug or its substitution with another drug and extension of the preoperative period. In addition to the aforementioned causes of postoperative hemorrhages, several authors [6] mention other factors such as installation of more than one stent per aneurysm, presence of pre- and postaneurismatic stenoses of the parent vessel, which required additional dilatation (hyperperfusion syndrome), perforation of small branches by delivery device during catheterization of the vessel above the aneurysm, hemorrhagic transformation of the ischemic lesion. In our series, there were 2 (0.9%) cases of hemorrhagic complications associated with perforation of the artery distal of the aneurysm.

Ischemic complications may be associated with in-stent thrombosis, disruption of blood circulation in the branches of the parent vessel or thromboembolic events. These complications are closely associated with incomplete expansion of the stent at the time of implantation and inadequate compliance with the antithrombotic protocol. In case of properly implanted stents, the disruption of the blood flow in small branches is extremely rare and only few such cases are described in the literature [8]. In our series, there were no early postoperative complications of this kind. In the late period, they were observed in 2 patients. In another 2 patients, ischemic disorders were caused by discontinuation of antiplatelet therapy or its non-systematic administration. In one case, the renewal and extension of the drug administration led to the regression of symptoms. In case of fusiform aneurysms with incomplete apposition of the stent to the artery walls, the authors recommend lifelong antiplatelet therapy for the prevention of such events [14, 18].

The maximum deceleration of blood flow in the aneurysm is the expected outcome, but it can lead to very rapid thrombosis of the aneurysm, followed by its condensation. In case of large and giant aneurysms, this effect can increase the mass effect on the surrounding structures of the brain and cranial nerves, exacerbating focal neurological symptoms. The observed progression of visual disorders in the long term was noted in patients with confirmed complete occlusion of the aneurysm (2 patients). We attribute this to the increased pressure on the optic nerve by a quickly thrombosing aneurysm.

All studies of the use of FDSs focus on various technical details, nature of the performed surgeries and their outcomes. The issue of selecting patients for the procedure receives insufficient attention. There are isolated cases of successful use of stents in the acute phase of the SAH (1 case in our series) [19]. However, most authors [13] believe that the SAH is a contraindication for this treatment. It is primarily due to the high risk of re-bleeding in the early postoperative period, since the blood flow to the aneurysm is not stopped. Against the background of dual antiplatelet therapy, this complication can be fatal. There is no consensus on the timing of operations in patients after the hemorrhage. Some researchers believe that FDS implantation can be scheduled no earlier than 2—3 months after the SAH [13, 14]. We believe this approach is appropriate in cases where the anatomical parameters of the aneurysm do not
allow for other (direct or endovascular) interventions. In our series, there were 21 such patients. All of them were operated on without complications in the period from 2 months to 7 years after the hemorrhage. Our analysis of the literature [7, 10, 12—17] was complicated by difficulty of comparing the results of the treatment, since the share of large and giant aneurysms in various publications varied from 11 to 82% of the total number of treated aneurysms. However, there is an apparent direct relationship between an index reflecting the number of stents per aneurysm and the number of adverse outcomes. The number of adverse outcomes increases if this parameter exceeded 1.8 and with increased proportion of large and giant aneurysms. In our series, which consisted of 100% of large and giant aneurysms, it amounted to 1.2. The incidence of adverse outcomes was low. It demonstrates that we have rarely used more than 1 stent per aneurysm thanks to the selection of the stent with appropriate length. In this context, the results of the PUFs research, where all aneurysms were large and giant and the ratio exceeded 3, are acceptable [16].

When comparing our data with the largest series [10, 12, 14—17, 20], it should be noted that the main indicators (completeness, disability/mortality) were on par with them. However, we should continue to monitor large number of patients in the long term. Currently, the catamnesis was collected only for 58% of patients (due to the objective difficulties), whereas in the foreign studies this figure is 80—90%.

When assessing the prospects of the FDS technology in the treatment of large and giant aneurysms, it should be noted that further improvement of treatment outcomes can be achieved through the improvement of the existing devices (increased flexibility of delivering system, possibility of coupling it with the stent, development of bifurcation stents).

**Conclusion**

1. FDS is a highly efficient device for remodeling of the arterial lumen at the level of large, giant and fusiform intracranial aneurysms that significantly reduces the number of deconstructive operations and decreases the risk of ischemic complications of endovascular treatment for this complex vascular pathology.

2. The use of FDSs requires mandatory compliance with the antithrombotic protocol, including objective control of patients’ sensitivity to the preoperative antplatelet therapy for prevention of thrombotic and hemorrhagic complications in the immediate postoperative and long-term periods.

3. When planning FDS surgeries one should consider topographic and anatomical features of clinically significant outgoing branches from the parent vessel or aneurysm. However, their presence in the area of the intended stent implantation is not a contraindication for the surgery because discirculation in the basin of these branches after the deployment of the stent is rare due to its semi-permeable design. Such situations require longer antplatelet therapy in the postoperative period.

4. Further study of long-term outcomes is required for more accurate assessment of the stability of aneurysm thrombosis with FDSs.

5. The use of the technique is prohibited in the treatment of aneurysms in acute hemorrhage stage. In the delayed period after a hemorrhage, the use of FDS can be considered on case-by-case basis, if there is no possibility to close the aneurysm by direct surgical or other endovascular methods.

**REFERENCES**


The treatment of large and giant intracranial aneurysms remains to be one of the most urgent problems of modern vascular neurosurgery.

In a number of cases, the use of a large number of coils may be associated with exacerbation of the mass effect, the compression of adjacent structures of the brain and aggravation of neurological symptoms.

The use of stent-grafts is not always feasible from a technical point of view. Rigid design of a graft makes it difficult to move it to the distal arteries of the brain. It requires the use of rather rigid guiding catheters of large diameter. In combination with a distal catheterization necessary for successful deployment of the stent-graft, it often leads to the development of pronounced spasm.

Deconstructive neurosurgical operations are also not without drawbacks. They require reliable estimate of reserves of collateral circulation and, in some cases, the establishment of arterial anastomosis.

Therefore, despite a number of limitations for use of the flow diverting stents, such as, in particular, the acute phase of subarachnoid hemorrhage, their introduction into clinical practice has significantly expanded treatment options for this type of aneurysms. The most important advantages of this method include the possibility to preserve normal antegrade blood flow in the parent artery, to maintain blood flow in the side branches, and better deliverability compared to stent-grafts.

The article presents the results of the use of flow-diverting stents in the treatment of 255 aneurysms in 210 patients. This sample size is sufficient to generate statistically valid conclusions and is comparable to the data obtained in the largest centers specializing in endovascular neurosurgery. The incidence and structure of complications are also comparable with the results published in reputable foreign journals. A significant number of patients have been followed up in the long term.

It is important that the authors devoted particular attention to the issue of resistance to the antiplatelet therapy and conducted a quantitative assessment of the preoperative suppression of aggregation, which is likely to have contributed to significant reduction in the incidence of immediate and delayed in-stent thrombosis.

**V.E. Ryabukhin** (Moscow, Russia)
Endovascular Treatment of Large and Giant Intracranial Aneurysms Using Stent Assistance


Burdenko Neurosurgical Institute, Moscow, Russia

Objective. The study objective was to evaluate the efficacy of occlusion of large and giant intracranial aneurysms with microcoils using stent assistance (SA). Material and methods. The study analyzed treatment outcomes in 37 patients (aged 18 to 72 years) with large (15—25 mm) and giant (more than 25 mm) intracranial aneurysms who were hospitalized to the Burdenko Institute of Neurosurgery between 2004 and 2014. Selection of patients for endovascular treatment using SA was based on the anatomical parameters of the aneurysm and carrying vessel. The dome-to-neck aneurysm ratio was the master factor. Occlusion of aneurysms was performed with coils of various configurations, including those with a biologically active coating. Self-expanding stents with both an open-cell and closed-cell design were used for SA. Results of surgery for large and giant aneurysms were evaluated by control angiography immediately after aneurysm occlusion. The condition of patients with unruptured aneurysms as well as with ruptured aneurysm in the “cold” period was evaluated by using the modified Rankin scale. The condition of patients in the acute period of SAH was evaluated by using the Hunt and Hess scale. Results. Technical success (successful implantation of stents and coils with total or subtotal occlusion of the aneurysm) amounted to 94.5%. Postoperative disability was 2.7%; mortality was 2.7%. Twenty-eight patients were followed-up for the period of 5 to 84 months (mean 20 months). In the long-term period, the total and subtotal occlusion rate, including results of re-operations, amounted to 90%. Long-term disability was 10.7%, and mortality was 3.5%. Conclusion. Stent assistance enables achieving total or subtotal occlusion of large and giant aneurysms in 90% of cases. In certain clinical situations, stent assistance is an alternative to other existing techniques.

Keywords: intracranial aneurysm, giant aneurysm, stent assistance, microcoil occlusion.

Considerable experience of endovascular treatment of cerebral aneurysms has been gained since introduction of a balloon catheter technique in the early 1970s (F.A. Serbinenko) and detachable microcoils in the early 1990s (G. Guglielmi). Along with clinical experience, instrumental facilities have been constantly improved, and coils of various configurations have been developed, which has expanded the indications for endovascular interventions. However, problems of endovascular treatment of wide-neck aneurysms as well as large and giant aneurysms have remained. It was found that the rate of wide-neck aneurysm recanalization for subtotal occlusion amounts to 37%, and the rate of large and giant aneurysm recanalization amounts to 90% [1—3]. These indicators are directly related to the aneurysm dome and neck size. The larger the aneurysm size and the wider the aneurysm neck are, the higher the probability of delayed recanalization is. In addition, the extent of aneurysm occlusion is of substantial importance [4].

The use of a balloon-assisted technique, which was introduced into clinical practice by J. Moret et al. [5], increased the extent of occlusion of wide-neck aneurysms. On the basis of experience of treating 56 patients, the authors demonstrated good treatment outcomes: total aneurysm occlusion was achieved in 77% of cases; subtotal occlusion was in 17% of cases; partial occlusion was in 6% of cases. Complications developed in 1% of cases; there were no deaths. However, this technique has drawbacks, including the need for long-term occlusion of the carrying vessel, a possibility of aneurysm rupture during rapid balloon inflating, and also the formation of thrombi proximal to the balloon.

Further attempts to improve treatment outcomes led to the development of special nitinol intracranial stents in the early 2000s. The first series of successful application of these stents was published by R. Benitez et al. [6]. The rate of total occlusion of wide-neck aneurysms using stents increased almost 2 times (73%), with the complication rate being 11%. In recent years, the stent design, delivery systems, and range of stent sizes have been varied. This greatly has increased the efficacy of stent application [7—9].

The use of stents involves antiplatelet therapy both in the preoperative period and in the postoperative period. This fact limits application of the technique in the acute period of aneurysm rupture in patients with concomitant pathology accompanied by hemorrhagic syndrome as well as in some patients with systemic hemostatic disturbances.

The use of balloon- and stent-assisted techniques is characterized by a somewhat larger number of complications compared to conventional aneurysm occlusion with microcoils [10—12]. The most typical complications include thromboembolism (18%) and intraoperative aneurysm ruptures associated with balloon inflation near the neck. Despite this, the techniques undoubtedly have some advantages in certain cases, and continuous improvement of the devices and ways of their application reduces the negative effects of surgery. Given the advantages and disadvantages of each of the assisting
techniques, their rational application, depending on a particular situation, enables achieving a positive result.

According to the literature, assisting techniques are often used to treat small, wide-neck aneurysms. However, generalized information on the efficacy of these techniques in treatment of large and giant aneurysms is scarce.

The purpose of this work was to evaluate the efficacy of occlusion of large and giant intracranial aneurysms with microcoils using stent-assisted techniques.

Material and Methods

The study was based on analysis of treatment outcomes in 37 patients (aged 18 to 72 years) with large (15–25 mm) and giant (more than 25 mm) intracranial aneurysms who were hospitalized to the Burdenko Neurosurgical Institute between 2004 and 2014. The male:female ratio was 1.1:1 (14 males and 23 females). Patients aged 41 to 60 years comprised the vast majority (25 patients). There were 8 patients under the age of 40 years and 4 patients older than 60 years of age.

Selection of patients for endovascular treatment using stent assistance (SA) was made based on anatomical parameters of the aneurysm and carrying vessel. The dome-to-neck aneurysm ratio was the master factor. Surgery using SA was indicated for the ratio of less than 2.

Twenty-nine patients had large aneurysms, and 8 patients had giant aneurysms. In 11 patients, aneurysms were multiple: along with large and giant aneurysms, the patients were detected with 18 medium and small aneurysms, which required various endovascular or direct surgical interventions. Thus, 37 patients were detected with a total of 55 aneurysms. The localization of large and giant aneurysms is shown in Figure 1.

The asymptomatic disease course was observed in 6 patients. Fourteen patients had intracranial hemorrhage; 4 of them were operated on in the acute period. The mean time since hemorrhage in patients operated on in the “cold” period was 32 months (2 to 120 months). Pseudotumor disease was observed in 16 patients, and transient ischemic attacks were observed in 1 patient. In these cases, the mean time of clinical manifestations before surgery was 8.4 months (1 to 38 months). Seven patients had hypertension.

Angiographic examination and endovascular surgery were performed using digital subtraction angiography (DSA) on an Axiom Artis BA biplane angiography system (Siemens), which enables working in the roadmap mode. All patients underwent 3D-rotational angiography. The aneurysm parameters were examined using a Leonardo 3D-station. In addition to studying the anatomical aneurysm parameters, the state of the circle of Willis was examined for possible or unintended occlusion of the carrying vessel.

Endovascular surgery was performed using the transfemoral approach. Local anesthesia with intravenous sedation (until 2008) and intubation anesthesia (mainly after 2008) were used as an anesthetic support. All patients who were planned for stent implantation were subjected to double antiplatelet therapy (75 mg/day of plavix and 100 mg/day of thrombo-ASS) 72 h before surgery and for 6 months after it. After puncture of the femoral artery, a heparin bolus was administered (5,000 U intravenously). Indications for additional administration of heparin were determined based on the activated clotting time (ACT). The target values were maintained at the level of 180—200 s.

Aneurysm occlusion was performed with microcoils of various configurations, including those with a biologically active coating: MDS (Balt, France); Matrix 2, GDC (Boston Scientific, USA); AXIUM (ev3, USA). Stent assistance was carried out using self-expanding stents with both an open (Neuroform 2—3, Boston Scientific, USA) and closed (Enterprise, Codman, USA) cell design.

All large and giant aneurysms (37) were occluded using stent assistance (of them, endovascular surgery in 3 cases was performed after failed or incomplete clipping). The other aneurysms were treated using various techniques, including microcoil occlusion, stent- or balloon-assisted occlusion, carrying vessel occlusion as well as direct interventions. Totally, 54 aneurysms were operated on: the endovascular technique was used in 42 cases, and the direct technique was used in 12 cases. One medium aneurysm in the extracranial segment of the internal carotid artery (ICA) was not operated.

The results of surgery for large and giant aneurysms were evaluated on the basis of control angiography immediately after aneurysm occlusion. Occlusion was considered to be total in the case of lacking aneurysm opacification, with preservation of blood flow in the carrying vessel, as well as in the case of carrying vessel occlusion. Subtotal occlusion was characterized by opacification in the region near the aneurysm neck. Partial occlusion was characterized by penetration of a contrast agent through the microcoils into the aneurysm body.

The condition of patients with unruptured aneurysms as well as with ruptured aneurysms in the “cold” period was assessed before and after surgery by using the modified Rankin Scale (mRS). Most patients had no or minimal neurological symptoms. The condition of patients in the acute period of subarachnoid hemorrhage (SAH) was evaluated by using the Hunt and Hess scale (Fig. 2).

Results

Stent-assisted occlusion of aneurysms was performed in several ways. The first technique included stent implantation and subsequent catheterization of the aneurysm cavity via stent cells (Fig. 3a). The second technique included pre-catheterization of the aneurysm cavity with a microcatheter. Then, a stent was placed at
the aneurysm neck level (Fig. 3b). In this case, a microcoil delivery catheter was located between the stent and the vessel wall, and its tip was in the aneurysm cavity. This technique avoided complicated passing a catheter through the stent cells.

The third technique was used for occlusion of basilar artery (BA) bifurcation aneurysms (Y-stenting). The key point of the technique was sequential catheterization and stenting of each posterior cerebral artery (PCA) through the main artery. Then, catheterization of the aneurysm and its occlusion with microcoils were performed. This technique enables simultaneous remodeling of the ostium of both PCAs and, thereby, prevents their unintended occlusion (Fig. 4).

The fourth method (waffle cone technique) was used to occlude aneurysms located at the BA bifurcation when the branching angle of PCA prevented its catheterization: the proximal portion of the stent was placed into the aneurysm through the carrying vessel (Fig. 5), and then catheterization of the aneurysm and its occlusion with microcoils were performed.

**Immediate outcomes of surgery**

The use of stents was initially planned in most patients. The patients underwent planned pre- and postoperative antiplatelet therapy. In three cases, stents were implanted due to displacement of coils during primary aneurysm occlusion with microcoils. These patients as well as patients in the acute SAH period (5) were treated with direct anticoagulants (low molecular weight heparin) and disaggregants within the next 2 days. Then, the patients received disaggregants in the usual regimen.

**Technical outcomes of surgery.** Forty stents were used for treatment of 37 large and giant aneurysms. Of these, 13 were Neuroform stents, and 27 were Enterprise stents. The first technique (catheterization of the aneurysm, followed by stent implantation) was used in 10 patients; the second technique (stent implantation followed by catheterization of the aneurysm) was used in 17 patients. Five patients underwent stent implantation using the waffle cone technique. Y-stenting was used in 2 patients with large and giant aneurysms of the BA bifurcation. In one case, a combination of two techniques was used: Y-stenting and the waffle cone technique (one of the stents was placed from BA to PCA, and the second stent was placed from BA into the aneurysm).

In 9 patients, aneurysms contained thrombotic masses. In 27 patients, aneurysm occlusion was performed immediately after stent placement. In 10 patients, aneurysm occlusion with microcoils was performed a few months after stent implantation. This was due to difficulties of guiding a microcatheter through a stent, related to the threat of stent displacement, which occurred during the first stage. After this period, when complete stent endothelialization occurred, guiding the microcatheter was not accompanied by stent...
displacement. Delayed occlusion of the aneurysm was performed in the period from 1 to 10 months (mean 4.3 months). In the delayed period, one more patient was implanted with a second stent because of displacement of the first stent.

Reconstructive surgery was performed in 33 patients, and deconstructive surgery was performed in 3 patients. Deconstructive operations were carried out when adequate stent placement was impossible (1 case) or in the case of technical failures, which are described below. In one case, asymptomatic thrombosis of the stent with total occlusion of the aneurysm was observed, which was detected during control AG 3 days after surgery. According to angiography, total and subtotal aneurysm occlusion was achieved in most cases (Fig. 6).

Technical complications during stent implantation occurred in 2 patients and were associated with stent migration. In both cases, stents were removed. Then, routine occlusion of the carrying vessel with preliminary formation of an extra-intracranial microanastomosis was performed.

During placement of microcoils, coil migration and catching on the stent cells during microcatheter deployment into the carrying vessel lumen occurred in one case. An attempt to remove the microcoil caused stretching of the microcoil proximal end and its spontaneous detaching from the pusher. A free coil portion was moved into the external carotid artery (ECA); the ICA lumen was fully preserved.

Intra-operative thromboembolic complications were observed in 2 cases. One patient had acute stent thrombosis after occlusion of the aneurysm cavity due to inadequate following the antithrombotic protocol (Fig. 7). In the second case, thromboembolism from the aneurysm occurred during its catheterization. In both cases, intra-arterial local thrombolytic therapy combined with intravenous thrombolysis was performed. As a result, complete recanalization of vessels was achieved in both cases.

Thus, technical success (successful implantation of stents and coils with total or subtotal aneurysm occlusion) amounted to 94.5%.

Clinical outcomes of surgery. Postoperatively, the condition of patients remained at the baseline level in

![Fig. 3. Stent-assisted technique.](image3.png)
Scheme. See explanations in the text.

![Fig. 4. Y-stenting technique.](image4.png)
Scheme. See explanations in the text.
most cases (29 patients). Improvement of the condition (partial regression of symptoms) in the early postoperative period was observed in 1 patient. Another female patient had worsening of the condition due to increased compression of surrounding structures. Symptoms regressed in the course of conservative therapy. Three patients complained of emergence or worsening of headaches, which significantly regressed to the time of discharge. Another patient developed ischemic stroke in the basal ganglia region with pronounced focal neurological symptoms after discharge from the hospital, on the 5th postoperative day. Intra-operative thromboembolic complications, which developed in 2 cases, did not lead to neurological deficit.

One patient with a giant basilar artery bifurcation aneurysm died. The patient underwent total aneurysm occlusion with microcoils using stent assistance (waffle cone-like). Postoperatively, the patient developed brain stem symptoms due to increased compression of surrounding structures by dense aneurysm mass. Because of aggravation of obstructive hydrocephalus, an external ventricular drain was placed on the 3rd day. After ventricular drain placement, on the background of disaggregant therapy, a hematoma formed along the shaft channel. The patient died from brain edema and herniation on the 5th day after surgery.

Therefore, postoperative disability amounted to 2.7%, and mortality was 2.7%.

**Long-term treatment outcomes.** Twenty eight patients were followed-up for the period of 5 to 84 months (mean 20 months). AG control (selective cerebral AG) was performed in 13 cases; MRI angiography was used in 6 cases; SCT angiography was used in 2 cases. In the remaining 7 cases, only clinical data were obtained. Improvement of the angiographic picture was observed in 3 patients: conversion from subtotal to total occlusion of the aneurysm occurred in 2 patients 9 and 36 months after surgery; conversion from partial to subtotal occlusion of the aneurysm occurred in 1 patient 15 months after surgery. In 10 cases, a stable angiographic picture (mainly in the case of total occlusion) was observed. Worsening of the angiographic picture was observed in 9 cases: total occlusion converted to subtotal occlusion of the aneurysm in 5 cases after 6—34 months; subtotal occlusion converted to partial occlusion in 4 cases 6—84 months after surgery. Six patients underwent re-operations. In one case, deconstructive operation was performed; in the other cases, a residual part of the aneurysm was occluded with microcoils. Three patients were still followed-up.

Therefore, the rate of total and subtotal occlusion, including the results of re-operations, in the long term period amounted to 90%.

The clinical status of 19 patients in the long term remained stable in most cases. In 6 patients, improvement of the state in the form of a partial or complete regression of existing symptoms was observed. In 3 patients, worsening of the state was observed, which was associated with acute ischemic stroke (AIS) on the operated aneurysm side (2 cases) or with aneurysm growth.
(1 case). One female patient died at the age of 73 years, 10 months after surgery, for unclear reasons.

In the long-term period, disability amounted to 10.7%, and mortality amounted to 3.5%.

**Discussion**

The emergence and introduction of stent-assisted and balloon-assisted techniques expanded the indications for endovascular treatment of large and giant aneurysms. This was especially clearly seen in the period before the advent of flow-diverting stents (FDSs) when the only available treatment of large and giant wide-neck aneurysms was occlusion of the carrying vessel (deconstructive surgery). In our series, 11 patients were operated on before this period. Stent assistance was the only alternative to deconstructive surgery in these patients. However, most patients of our group were operated on since 2009 (period of extensive FDS use).

In our view, there is a certain niche in the treatment of large and giant aneurysms, which can be firmly occupied by stent- and balloon-assisted techniques. It primarily includes patients with ruptured aneurysms in the acute and immediate (up to 6 months) “cold” periods of hemorrhage. These patients are contraindicated for placing FDS due to a high risk of aneurysm rerupture. This group may also include aneurysms with a diverticulum, which is usually the most likely rupture site. Furthermore, aneurysm occlusion using stent- and balloon-assisted techniques can be performed in cases where the anatomo-topographic parameters of vessels prevent FDS implantation. These include the closed carotid siphon, pronounced tortuosity of the extracranial segments of the brachiocephalic arteries, a large difference in the diameter between the distal and proximal segments of the stented artery, a small diameter of the carrying artery, and the bifurcation area.

Analysis of recent year publications indicates an increase in the number of surgeries using stent-assisted techniques [13—17]. Our results are consistent with the results presented in the literature. However, these techniques have a number of limitations. This is primarily related to a potential increase in compression of surrounding brain structures. This is the most urgent problem in patients suffering primarily from the space-occupying effect of the aneurysm. Partially, the problem can be resolved by means of microcoils coated with a biodegradable polymer, which is completely reabsorbed for the next 6 months. This reduces the aneurysm size. However, the use of these microcoils increases the rate of aneurysm recanalization. In addition, tight tamponade of the aneurysm cavity containing thrombi (25% of aneurysms in our series) is often not possible, and microcoils usually “fall in” the thrombotic mass in the long-term period. This causes aneurysm recanalization, which may lead to an increase in the aneurysm size. In this respect, these techniques fall short to endovascular FDS surgeries.

The main technical problems occurred at the primary stage of mastering the technique (for the first year) and were associated with the use of the first generation of Neuroform stents. This fact reflects not only a lack of experience of stenting at the first stage but also disadvantages of this stent design, which has an open cell type and is not bound tightly to the delivery system. The advent of stents with a closed cell design significantly reduced the number of technical complications. In this regard, we prefer Enterprise stents.

Further improvement of the quality of surgeries using stent-assistance is related to solving a number of problems. The most important problem of them is prevention of thromboembolic complications. In our series, this was the female patient (who initially was not a candidate for stenting, but was implanted with a stent because of a complex intraoperative situation) who developed stent thrombosis. This fact is confirmed by the data of H. Henkes et al. [18] and V. Katsaridis et al. [19] in whose studies no preparation of patients before stent placement was performed. Most of these patients were operated on in the acute or subacute period of SAH.

![Fig. 7. Angiograms of a female patient with acute intraoperative stent thrombosis.](image)
percentage of thrombotic complications amounted to 23—35%. In our series, no such complications were observed in cases where patients underwent complete preoperative pharmacological preparation. In cases of ruptured aneurysms, preoperative preparation may complicate the course of repeated hemorrhages, which are more common for ruptured aneurysms than for unruptured aneurysms. Usually, hemorrhages occurring during this therapy are fatal. The literature does not provide an unambiguous answer to the question about the possibility of using stents in the acute SAH period. Some authors consider it possible to use high doses of plavix on the eve of surgery (single administration of a 3—4-fold daily dose) or directly on the operating table if a decision to use a stent is made after angiographic examination. However, the maximum therapeutic effect of antiplatelet therapy is known to occur on the 3rd day, on average; therefore, anticoagulant therapy in the postoperative period should be started at least on the 2nd day, before the plavix effect development. This requirement can be successfully implemented only in those cases where the aneurysm is totally occluded during endovascular intervention, which is not always predictable. Other authors [20—22] suggest partial occlusion of the aneurysm body or the most “problematic” aneurysm parts (e.g., the diverticula area), followed by complete preparation of the patient and total occlusion of the aneurysm at the second stage, after stent implantation. However, this technique is also not always implementable since fixation of microcoils only at the “problematic” site of the wide-neck aneurysm is usually impossible. Anyway, the treatment tactics for these aneurysms should be chosen individually for each case.

Another problem, which is associated with the use of stents, is the feature of initial stent positioning. The greatest difficulties, according to both publications and our experience, are associated with the use of Neuroform stents lacking rigid coupling to the pusher, which consequently prevents their reposition in the case of inadequate implantation [23]. We did not find in the literature any recommendations for resolving this problem. In a series of our observations, we were able to remove a stent in two cases. We did not find similar examples in the literature. Later, these patients underwent

---

Fig. 8. Angiograms of a female patient with a large BA bifurcation aneurysm.

a — initial angiogram in the frontal projection; b — control angiogram after total aneurysm occlusion with microcoils using stent-assistance (Y-stenting); c — angiogram without subtraction. Stent contours are shown in white (Neutoform) and black (Enterprise) dotted lines, respectively.
intended occlusion of the carrying artery with preliminary creation of an extracranial microanastomosis. This problem was resolved in 2007 when Enterprise stents, which we have preferred to date, entered the domestic market.

However, the open cell design enables using Neuroform stents for Y-stenting of a basilar artery or internal carotid artery bifurcation aneurysm with a wide neck [24]. We used this technique (combination of Neuroform and Enterprise stents) in 2 patients with a good angiographic and clinical outcome (Fig. 8).

Conclusions

1. Stent-assistance enables achieving total or subtotal occlusion of large and giant aneurysms in 90% of cases. In certain clinical situations, it is an alternative to other existing techniques.
2. The use of stent-assisted techniques is preferable for large and giant aneurysms with complex anatomy where the use of flow-diverting stents is unadvisable (closed carotid siphon, bifurcation aneurysms, small diameter arteries, or arteries with a large diameter difference).
3. Planning of surgery with intracranial stents in the case of unruptured aneurysms should be based on thorough compliance with a preoperative antiplatelet protocol to prevent thromboembolic complications.
4. The use of stent-assistance in patients with ruptured aneurysms in the acute period of SAH requires individual planning and use of the antithrombotic protocol.

REFERENCES


The work by S.R. Arustamyan et al. is devoted to analyzing the results of using stent-assisted techniques in treatment of 37 patients with large and giant intracranial aneurysms. These patients were detected with 55 aneurysms, 42 of which were subjected to endovascular intervention, and the others were subjected to direct surgical intervention.

Endovascular interventions were performed using various stent-assisted techniques, which are presented in the article by understandable diagrams and explanations. The use of stent-assisted techniques for placing microcoils to the aneurysm cavity led to complete and subtotal occlusion in 94.5% of cases in the immediate postoperative period. Mortality and neurological complications due to circulatory disturbances amounted to 2.7% each.

Neuroimaging examinations were conducted only in 21 patients in the long-term postoperative period. Improvement of the angiographic picture was observed in 3 patients, and worsening, i.e. partial recanalization of the aneurysm, occurred in 9 cases. Repeated endovascular interventions were performed in 6 cases, and, according to the authors, the final outcome in the presented study amounted to 90% of total and subtotal occlusions, with mortality and morbidity being 3.5% and 10.7%, respectively.

The authors pay great attention to preparation of patients for endovascular stent-assisted aneurysm occlusions and discuss in detail the need for antiplatelet therapy, emphasizing the complexity of its implementation and existing risks in the acute period of subarachnoid hemorrhage. The article also discusses various aspects of combined application of various stent-assisted techniques and provides comparative evaluation of stents from various manufacturers.

On the basis of good results on the use of stent-assistance for microcoil occlusion of large and giant cerebral aneurysms, S.R. Arustamyan et al. emphasize the significance and role of the presented technique. Stent-assisted coil occlusion is of great importance in the case of inability to use, for various reasons, the so-called pipeline stents as well as in some specific cases in the acute period of subarachnoid hemorrhage.

This work, which is based on the authors’ experience, is a good example of careful and sequential analysis of the authors’ methodological techniques and available literature data for formulation of guidelines specifying application of a particular neurosurgical technique. Not all aspects of endovascular stent-assisted embolization of large and giant cerebral aneurysms are duly covered in the article. For example, evolution of the size of total/subtotal thrombosed aneurysms, neural structure compression associated with thrombosis of occluded aneurysms, the place and role of vascular bypass, simultaneous exclusion of medium aneurysms, etc. This “incompleteness” of the study just emphasizes the complexity of surgical treatment of large and giant aneurysms and also indicates the need for further publications summarizing the results of medical practice and scientific research.

Yu.A. Grigoryan (Moscow, Russia)
Supracerebellar Transtentorial Approach to Tumors of the Posterior Mediobasal Temporal Region


Burdenko Neurosurgical Institute, Moscow, Russia

Objective. Despite the advances in microsurgery, the choice of the most adequate approach to the posterior portion of the medial temporal region (MTR) remains a formidable challenge. The supracerebellar transtentorial (SCTT) approach is considered to provide the optimal balance among retraction, incision, and resection of brain tissues for accessing the posterior MTR. Here, we present a consecutive series of 20 patients who were operated on using the SCTT approach.

Material and methods. Twenty patients were operated on for glial tumors affecting the posterior MTR using the SCTT approach at the Neurosurgical Institute between 2006 and 2014. The mean age of patients was 20 years. Benign tumors were predominant (18 cases). Results. Resection of the posterior and middle MTR was performed in 16 patients. The anterior MTR was accessed through the SCTT approach in 1 patient only; in 2 patients, the SCTT route was combined with the infraoccipital approach, which enabled resection of the uncus and amygdala. Complications occurred in 4 patients and were associated with cerebellar edema in 2 cases and with ischemia in the basal ganglia in 2 cases; 1 of these patients developed a permanent neurological deficit in the form of hemiparesis and complete hemianopia. In 8 cases, tumors manifested as drug-resistant temporal lobe epilepsy; in 6 patients, Engel class 1 or 2 outcomes were observed within the 1st postoperative year. Conclusion. The SCTT approach can be a reliable alternative to transcortical approaches to tumors of the posterior and middle MTR. However, the anterior MTR cannot be safely reached through the SCTT approach because cerebellar retraction is increased as resection is extended to the anterior MTR. Anterior MTR structures can be removed using a combination of the supracerebellar and infraoccipital approaches or a two-stage resection.

Keywords: epilepsy surgery, amygdalohippocampectomy, supracerebellar approach, brain tumors.

Abbreviations

MTR — medial temporal region;
SCTT — supracerebellar transtentorial;
DNET — dysembryoplastic neuroepithelial tumor.

An approach to the medial temporal region (MTR) places the surgeon before a challenge of minimal injury to the eloquent neocortex and subcortical conducting pathways limiting the deep-seated portions of the temporal lobe, which, according to some authors [1—4], can be reached through the supracerebellar transtentorial (SCTT) approach. This surgical approach was pioneered by M. Yasargil and K. Voigt [5] in 1976 who used it to remove a cavernoma of the posterior portions of the parahippocampal gyrus. Since 2001, publications began to appear that reported on small series of surgical interventions using this approach to treat patients with vascular pathology, MTR tumors, and medial temporal lobe epilepsy [2—5]. This publication presents experience of the Burdenko Neurosurgical Institute in using the SCTT approach in surgery for tumors of the medial portions of the temporal lobe.

Material and Methods

Medial temporal region anatomy

The medial temporal lobe, which is medially limited by the lateral wall of the cavernous sinus and the carotid, crural, ambient, and quadrigeminal cisterns and laterally limited by the rhinal and collateral sulci, is conditionally divided into three portions: anterior portion running from the origin of the rhinal sulcus to the level of the beginning of the choroid plexus in the temporal horn; middle portion extending from the inferior choroidal point to the quadrigeminal plate; posterior portion going to the borders with the isthmus of the cingulate gyrus (Fig. 1). The isthmus of the cingulate gyrus is situated between the parahippocampal and cingulate gyri and is formed posteriorly and inferiorly to the splenium of the corpus callosum.

Surgical technique

In all cases, we used a sitting position, producing a midline skin incision from the point of 3 cm above the inion to the C2 level to widely expose the squama of the occipital bone. Craniotomy is performed so as to completely expose the confluence of sinuses and transverse sinuses up to their junction to the sigmoid sinuses (Fig. 2). At these stages of soft tissue dissection and craniotomy, special attention is paid to the control of air embolism: the CO$_2$ level in the expired air is monitored, the emissary veins are closed with wax, and compression of the neck veins is periodically conducted to detect emissary veins.

© Group of authors, 2015

e-mail: dmkopachev@gmail.com
The dura mater over the cerebellar hemisphere is opened in a C-shaped manner (with the base facing the transverse sinuses), sutured, and pulled up using tack-up sutures to increase room for the approach, for which purpose, as was said above, it is important to expose the transverse sinus and confluence of sinuses. An approach to the quadrigeminal and ambient cisterns is performed on the side where the access to MTR is planned. At this stage, a lateral group of veins running from the tentorium onto the cerebellum may impede the access. Preservation of these veins is advisable, although their coagulation and transection are usually not accompanied by complications. To preserve the veins, they are wrapped with pieces of hemostatic gauze or cotton.

The arachnoid mater is opened by sharp dissection; in this case, brain tissue relaxation occurs as the cerebrospinal fluid is aspirated. After the arachnoid dissection is made, the superior colliculi, vein of Galen, pineal gland, trochlear nerve, and isthmus of the cingulate gyrus are visualized on the approach side. The tentorium is incised 3—4 cm posterior to its edge, and the incision is extended toward the tentorial incisura, medially. Care should be taken when approaching the tentorial edge because of possible damage to the trochlear nerve in this area. Free edges of the incised tentorium are coagulated; in addition, its wide excision is possible to provide a more extensive opening of the basal surface of the temporal and occipital lobes. Variants of tentorial incision/excision may be changed in the presence of tentorial venous sinuses, which most often occur in the medial third of the tentorium; if the sinuses are cut off, the incision edges should be coagulated and clipped. The surgeon and anesthetist should be aware that incision of the tentorium, which receives rich innervation from the trigeminal nerve system, may be accompanied by temporary bradycardia or arrhythmia. After the tentorial incision, the surface of the fusiform gyrus and posterior MTR is extensively exposed (Fig. 3).

The key point of this surgical stage is identification of the following structures to serve the landmarks in the operative field (in the medial-lateral direction): quadrigeminal plate, parahippocampal gyrus, collateral sulcus, and fusiform gyrus. In the case of a small-sized tumor, arachnoid dissection along the ambient cistern can be used to visualize the P2—P3 segments of the posterior cerebral arteries and the vein of Rosenthal. If a tumor lesion involves the fusiform gyrus, tumor removal can be started with resection in its projection.

*Fig. 1. Anatomy of the medial temporal region (MTR).*
A — anterior MTR, M — middle MTR, P — posterior MTR, ACA — anterior cerebral artery, MCA — middle cerebral artery, PCA — posterior cerebral artery, PG — parahippocampal gyrus, FugG — fusiform gyrus, LinG — lingual gyrus, CinG — cingulate gyrus, RinS — rhinal sulcus, ColS — collateral sulcus, OctS — occipitotemporal sulcus, CalS — calcarine sulcus, Unc — uncus, III — oculomotor nerve. The area accessible for resection through the SCTT approach is shown in green. Dashed lines indicate the boundaries of portions of the medial temporal region: 1 — line passing through the beginning of the rhinal sulcus, 2 — line passing through the origin of the choroid plexus in the temporal horn (not shown), 3 — line passing through the quadrigeminal plate, 4 — line passing through the isthmus of the cingulate gyrus.
culliculi, which serve the posterior border in hippocampectomy. Entering the temporal horn of the lateral ventricle is of crucial importance for the resection procedure since it enables visualization of the ventricular part of the hippocampal body and head and also the choroid plexus with the choroidal fissure (Fig. 4). The tumor is resected subpially, along the ambient cistern, which serves the medial border of resection, while the hippocampal arteries arising from the P2 segment of the posterior cerebral artery are coagulated and cut off. Hippocampectomy can be performed en bloc after dissection of the choroidal fissure between the hippocampal fimbriae and choroid plexus.

It should be noted that the anterior MTR lies behind the petrous pyramid and can not be directly visualized through the SCTT approach. If resection of the uncus is required, the infraoccipital approach can be used. For this purpose, the surgeon performs craniotomy to expose the pole of the occipital lobe. After resecting the posterior and middle MTR portions through the SCTT approach, the dura mater is incised above the occipital lobe, which is then lifted up by a spatula. Resection the uncus and amygdala is made through the existing operative corridor, which requires minimal retraction of the occipital lobe. It should be noted that the surgical wound depth for uncus resection is about 9 cm from the pole of the occipital lobe, which requires the use of the longest microinstruments.

Results

Twenty patients were operated on using the SCTT approach in the period between 2006 and 2013. A combination of the supracerebellar transtentorial and infraoccipital approaches was used in 2 patients. The age of patients ranged from 7 to 36 years (median 20 years). The male/female ratio was 1:1. Epileptic seizures were the key symptom in the clinical picture in all 20 patients. In 3 cases, homonymous hemianopia was observed. Total tumor resection was achieved in 8 patients, subtotal resection was in 11 patients, and partial resection was in 1 patient. Benign tumors were predominant (18 of 20 patients): piloid astrocytoma ($n=6$), ganglioglioma ($n=5$), pleomorphic xanthoastrocytoma ($n=3$), DNET ($n=1$), glial hyperplasia ($n=1$); 2 patients had diffuse astrocytomas (WHO Grade 2), and 2 patients had anaplastic astrocytomas (WHO Grade 3). The tumors affected the left hemisphere in 12 cases and the right hemisphere in 8 cases. The maximal tumor size, as determined by sagittal MRI scans in the FLAIR mode, ranged from 1.5 to 7.0 cm. As the tumor size increased, the tumors invaded the middle medial temporal region.

In 3 cases, tumors affected the anterior MTR only and were less than 1.5 cm in size. The posterior and middle MTR was affected in 10 cases; the tumor size was up to 2.5—3 cm. In 7 patients, the pathological process

![Fig. 2. a — craniotomy related to the SCTT approach.](image)

1 — occipital lobe, 2 — superior sagittal sinus, 3 — confluence of sinuses, 4 — transverse sinus, 5 — cerebellar hemisphere.

b — a scheme of the SCTT approach. The arrow indicates a trajectory. The dotted line indicates tentorial incision.

![Fig. 3. Parahippocampal and fusiform gyri after tentorial incision:](image)

PG — parahippocampal gyrus; FuG — fusiform gyrus.

If the surgery task includes hippocampal resection to stop epileptic seizures, the starting point of resection is the parahippocampal gyrus at the level of superior
involved all MTR portions, and the tumor size in these cases varied from 4 to 7 cm.

In 16 cases, resection of anterior MTR structures was not performed because of anatomical restrictions. A combination of the supracerebellar transtentorial and infracerebelical approaches was used in 2 patients to remove the anterior portions of the medial temporal region (uncus and amygdala). In 1 patient, the amygdala and hippocampal head were removed using the SCTT approach only (Table 1, Case 2). One of the patients had tumor recurrence after subtotal resection of a piloid astrocytoma, which required reoperation via the transcortical approach 5 months later.

Eight patients had drug-resistant epileptic seizures, which required not only complete tumor resection but also seizure control. The surgery outcome in these 8 patients was assessed by using the Engel scale by the end of the first postoperative year. Eight patients were followed-up for 1 year. Complete seizure cessation occurred in 4 patients (class I outcome); 2 patients had up to 3 seizures per year (class II outcome); in 2 patients, the seizure frequency was reduced by at least 50% per year (class III outcome). However, in one of the patients, who underwent subtotal removal of gangliocytoma of the hippocampus, there was a fatal outcome associated with epileptic seizure.

Complications were observed in 4 of 20 patients; in 2 cases, complications were associated with cerebellar edema, which was accompanied by a decrease in the consciousness level with signs of acute hydrocephalus (Table 1). In these two cases, the need for prolonged mechanical ventilation led to temporary tracheostomy. In 2 patients, a decreased consciousness level was accompanied by hemiparesis and was associated with ischemia of the posterior limb of the internal capsule, which was apparently associated with damage to the thalamogeniculate arteries arising from the posterior cerebral artery. Complete regression of hemiparesis was observed in 3 out of 4 cases.

Three patients had visual field disturbances before surgery. In the postoperative period, loss of visual fields was observed in 5 patients: superior quadrantic homonymous hemianopia occurred in 4 patients, and complete homonymous hemianopia occurred in 1 patient.

**Discussion**

**Choosing a surgical approach**

The complexity of choosing a surgical approach to the MTR is due to its great length in the anteroposterior direction and two bends: around the midbrain in the axial plane and around the petrous pyramid in the sagittal plane. These anatomical features greatly limit the possibility of approaching all parts of the region in one-stage through one surgical approach [2]. Various surgical approaches to the MTR may be divided into anterior, lateral, and posterior routes, with each of them having its own advantages and limitations [6].

The literature on surgery of the temporal lobe intensively debates on the choice of an approach that is associated with the minimal risk of injury to the optic radiation, namely the Meyer’s loop, which passes in the roof of the temporal horn of the lateral ventricle (Table 2) [6]. H. Manji et al. [13] demonstrated that the rate of visual field loss in surgery for temporal lobe epilepsy varied from 46 to 54%, but, despite cessation of seizures, 42% of patients failed the driving criteria adopted in Great Britain due to visual field defects. In the present study, the rate of postoperative visual field defects was 26% (5 of 19 patients). In this case, only 1 patient had the maximum degree of complete homonymous hemianopia; according to automated perimetry, incomplete superior quadrantic hemianopia was observed in 4 cases, which was not subjectively felt by these patients. According to the practical parameters of temporal lobe surgery, superior quadrantic hemianopia associated with drug-resistant epilepsy is not considered a complication [14].

**Complications associated with the supracerebellar transtentorial approach**

Complications associated with the SCTT approach may be caused by the patient position on the operating table, transection of the veins coming from the tentorium to the cerebellum, and tentorial incision. The patient sitting on the operating table is the best position, but it has risks of air embolism, with the rate varying from 2 to 76% [15—17]. However, current neuroanesthesia protocols enable reducing the rate of hemodynamically significant embolism to 0.5%, with a zero risk of complications [18]. No hemodynamically significant episodes of air embolism were observed in the present series.
The necessity of cutting off the veins coming from the cerebellum to the tentorium arises in 1/3 of cases and is not accompanied by complications. This is likely associated with the fact that a paramedian trajectory of the approach preserves a midline group of the vermian veins, which is sufficient for normal blood circulation in the cerebellum [19]. Impairment of venous circulation in the cerebellum is known to be exacerbated by its strong retraction. A position with the patient sitting on the operating table makes it possible not to use spatulas and to reduce brain retraction because the cerebellum moves away from the tentorium under the influence of gravity. The retraction strength and the risk of cerebellar edema increase as the surgeon proceeds to the junction of the anterior and middle portions of the MTR. In our opinion, the risk of cerebellar edema is minimal for resection of small tumors in the posterior MTR (Fig. 5). The risk of complications is maximal for total resection of large tumors involving the anterior MTR, with high vascularity and density (Fig. 6). Difficulties associated with tentorial incision may occur if the tentorium contains large venous lacunae/sinuses [20]. Tentorial incision should be planned with allowance for the anatomy of these lacunae, which should be preserved in the case of their large size. Also, when incising the anterior edge of the tentorium, the surgeon should first visualize the trochlear nerve to avoid damaging it [4]. The SCTT approach to the medial portions of the temporal lobe provides a narrow and deep operative corridor. U. Ture et al. [2] have noted that successful implementation of manipulations in these conditions can be achieved when the surgeon controls microscope functions (focus, zooming), keeping his hands in the surgical field, e.g., using a mouth switch device. In 13 patients, surgery was carried out using a Mari original device for hands-free control of an operating microscope, which significantly accelerated and facilitated the surgery [21].

**Epileptological outcome of surgery**

Concerning surgery of temporal lobe tumors, it should be emphasized that, in addition to the neuro-oncological aspect of treatment (making a histological diagnosis and complete tumor resection), there is also the epileptological aspect, which often comes to the fore because the most common cause of drug-resistant temporal lobe epilepsy is benign glioneuronal tumors (e.g., DNET and ganglioglioma) with an exceptionally favorable neurooncological prognosis [22, 23]. The complexity of the situation is due to the fact that the area of MRI-visualized anatomical changes does not always

---

**Table 1. Complications associated with the supracerebellar transtentorial approach**

<table>
<thead>
<tr>
<th>Age/gender</th>
<th>Maximum tumor size, cm</th>
<th>Histology</th>
<th>Complication</th>
<th>Neurovisualization data</th>
<th>Karnofsky scale score after six months</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 29/f</td>
<td>3</td>
<td>Piloid astrocytoma</td>
<td>Transient hemiparesis</td>
<td>Ischemic lesion in the posterior limb of the internal capsule</td>
<td>100</td>
</tr>
<tr>
<td>2 22/m</td>
<td>7</td>
<td>Gangliocytoma</td>
<td>Transient hemiparesis, sopor, noncommunicating hydrocephalus, tracheostomy</td>
<td>Cerebellar edema</td>
<td>100</td>
</tr>
<tr>
<td>3 15/m</td>
<td>3,1</td>
<td>Piloid astrocytoma</td>
<td>Transient hemiparesis, coma, noncommunicating hydrocephalus, tracheostomy</td>
<td>Cerebellar edema</td>
<td>100</td>
</tr>
<tr>
<td>4 14/f</td>
<td>3,7</td>
<td>Astrocytoma</td>
<td>Transient hemiparesis, complete hemianopia, sopor</td>
<td>Ischemic lesion in the posterior portions of the thalamus</td>
<td>70</td>
</tr>
</tbody>
</table>

**Table 2. The advantages and disadvantages of approaches to the MTR**

<table>
<thead>
<tr>
<th>Approach trajectory</th>
<th>Approach</th>
<th>Accessible MTR parts</th>
<th>Complications</th>
<th>Optic radiation injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>Transsylian</td>
<td>Anterior — middle</td>
<td>Vasospasm of vessels of the Sylvian fissure</td>
<td>46—56%</td>
</tr>
<tr>
<td></td>
<td>Transsylvian [7, 8]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transsylian transsternal [9]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transcortical [10]</td>
<td>Anterior — middle</td>
<td>Nerve III injury (9%), vasospasm</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Subtemporal [11]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral</td>
<td>Transcortical [10]</td>
<td>Anterior — middle</td>
<td>Neocortical injury</td>
<td>28—78%</td>
</tr>
<tr>
<td>Posterior</td>
<td>Occipital interhemispheric [12]</td>
<td>Posterior</td>
<td>Visual cortex injury</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>Supracerebellar transtentorial [2]</td>
<td>Anterior — middle</td>
<td>Risk of cerebellar edema</td>
<td>0—26%</td>
</tr>
</tbody>
</table>
Fig. 5. Piloid astrocytoma of the posteromedial portions of the left temporal lobe.
Preoperative axial sections: a — tumor of the posterior and middle MTR; b — a trajectory of the subtemporal approach to a tumor of the posterior portions of the left MTR. A localization of the tumor near the tentorial incisura will be associated with strong retraction of the temporal lobe: 1 — parahippocampal gyrus, 2 — fusiform gyrus, 3 — inferior temporal gyrus; c — postoperative MRI: the tumor is completely resected (contrast-enhanced T1-weighted image); d — amygdala (A) and hippocampal head (H) (T2 mode); e — a SCTT approach trajectory prevents resection of the MTR portions (shown in red) anterior to the origin of the choroid plexus (indicated by the arrow). Epileptological Engel class 1 outcome (complete cessation of seizures). The epilepsy duration is 1.5 years.
Fig. 6. Complications of the SCTT approach.

Ganglioastrocytoma of the medial temporal region (a) affecting its anterior and middle portions (indicated by arrows) and spreading to the triangle of the lateral ventricle (b). Removal of the tumor from the anterior MTR was associated with increased cerebellar retraction (Table 1, Case 2). Postoperative CT (c) reveals cerebellar edema and compression of the ambient cistern. A patient underwent placing an external ventricular drain due to the development of hydrocephalus. Six months later, MRI reveals complete tumor removal (d). Six months later, the Karnofsky scale score is 100.

coincide with the epileptogenic zone, which can be much larger. After analyzing the data of MRI and video-EEG monitoring with assessment of seizure semiotics, the surgeon and epileptologist can choose one of three variants of surgical treatment: tumor resection, anterior temporal lobectomy with partial tumor resection, and removal of the tumor, including resection of the uncus and amygdala using a combined approach. Resection of just a tumor of the posterior regions of the parahippocampal gyrus and hippocampus can be fully carried out both through the posterior approach and through the inferior temporal gyrus; however, in the latter case, the surgeon will have to use temporal lobe retraction, which is particularly risky when the dominant hemisphere is affected (Fig. 5b). Removal through the posterior approach prevents resection of the uncus,
Amygdala, and pole of the temporal lobe, i.e. a potentially larger epileptogenic zone, and, as a result, may not lead to adequate seizure control.

Persisting seizures are known to be a risk factor for sudden unexpected death in epilepsy (SUDEP), which occurred in one of the patients of this series [24]. One of the factors prognostically unfavorable for postoperative seizure control is a prolonged epilepsy period before surgery, which is likely related to the formation of a larger epileptic neural network, including not only the tumor-affected hippocampus but also the temporal lobe neocortex [25]. It should be noted that 2 of 8 patients with drug-resistant epilepsy and the least favorable outcome (Engel class 3) had the disease duration of more than 30 years (including the patient with SUDEP), while 5 patients with the class 1 and 2 outcomes had the epilepsy duration of 2.7 years, on average. This pattern could not be confirmed statistically due to a small number of patients; however, a long-term duration of epilepsy should orient the epileptologist and surgeon for planning a larger extent of resection, which is not limited to the tumor only.

Another approach to radical resection of MTR lesions is a combination of the supracerebellar transtentorial and supratentorial infraoccipital approaches (Fig. 7). A trajectory of the infraoccipital approach enables the surgeon to see the anterior MTR portions lying behind the petrous pyramid (Fig. 5e, shown in red). Although resection of the uncus through the infraoccipital approach, after removing the posterior hippocampal regions, requires occipital lobe retraction, but it does not damage the visual cortex because performed through the existing operative corridor, with the brain being relaxed. No postoperative complete homonymous hemianopia was observed in either of our two cases involving the combined approach.
Conclusion

The supracerebellar transtentorial approach is convenient for removing pathological lesions in the posterior and middle medial temporal regions. However, risks of cerebellar retraction, as well as and operative risks of the SCTT approach, increase as the neurosurgeon proceeds to the anterior MTR portions. The anterior medial temporal region can not be safely reached through the supracerebellar approach; if its resection is required, it is possible to combine the supracerebellar and infraoccipital approaches or to plan the second stage of surgery via the anterior approach when there is a persisting epileptogenic zone in the anterior portions of the medial temporal region or a residual tumor in it.

REFERENCES

The deep-seated localization of the medial temporal region along the critical neurovascular structures poses a non-trivial neurosurgical problem of a surgical approach to the region. The surgeon faces the problem of minimal injury to the functionally significant neocortex and conduction pathways of the temporal and occipital lobes covering the medial temporal area. The authors describe in detail the advantages and disadvantages of anterior and lateral approaches to the deep-seated regions of the temporal lobe. In their opinion, the most optimal approach to the posterior portions of the mediobasal temporal region is the supracerebellar transtentorial approach with tentorial incision. The main advantages of the technique undoubtedly include protection of the optic radiation from injury and no need for incision and retraction of the functionally significant lateral neocortex, especially in the dominant hemisphere. Nevertheless, the supracerebellar approach has drawbacks, which include, first, the need for surgery with the patient in a sitting position (with all anesthetic risks) and, second, the impossibility of removing the anterior portions of the temporal lobe. Attempts to remove the pole of the temporal lobe, uncus, and amygdala are accompanied by strong cerebellar retraction and a risk of cerebellar edema. The authors recommend limiting the use of the supracerebellar approach to resection of tumors in the posterior and middle parts of the hippocampus, and, if resection of the uncus and amygdala is necessary, using the infraoccipital approach simultaneously or planning the second stage of surgery through the lateral approach. In the present paper, the authors emphasize the epileptological aspect of treatment of temporal lobe tumors because a substantial fraction of patients had benign glioneuronal tumors, which are the most common cause of drug-resistant symptomatic epilepsy. In this respect, the authors attempt to assess the factors affecting the epileptological outcome of surgery and to answer the question if resection of just a tumor of the posterior hippocampus is sufficient to stop seizures, or the resection should include a greater amount of the potentially epileptogenic brain tissue (uncus, amygdala, temporal pole). A long history of epilepsy should orient the surgeon to resect not only the tumor but also the anterior portions of the temporal lobe; although, analysis of a larger number of patients is required to confirm this suggestion. Overall, the work is of great interest and importance for neurosurgeons, oncologists, and epileptologists.

V.L. Puchkov (Moscow, Russia)
Surgical Anatomy of the Insular Cortex

A.E. BYKANOV, D.I. PITSKHELAURI, G.F. DOBROVOL'SKIY, M.A. SHKARUBO

Burdenko Neurosurgical Institute, Moscow, Russia

Objective. The objective of this study was to investigate the surgical anatomy of the insular cortex, morphology and vascularization of the insula and adjacent opercula in terms of the transsylvian and transcortical approaches and to identify the permissible anatomical boundaries for resection of glial tumors of the insula. Material and methods. The study was conducted on 18 anatomical specimens fixed in an alcohol-glycerol solution. Perfusion of the internal carotid artery with red latex was used to study the arterial system. Dissection of the arteries and Sylvian fissure, investigation of the morphological features of the opercula, as well as simulation of the transsylvian and transcortical approaches to the insula were performed using a surgical microscope. Results. In the transsylvian approach, the anteroinferior part of the insula (including the limen insulae) is the most technically accessible area, whereas the superior parts of the insula are the least accessible areas. With tumors localized in the superior insula, the transcortical approach may be recommended, which, unlike the transsylvian approach, does not require significant retraction of the brain matter and provides larger surgical corridor. The transcortical approach, regardless of the insular region, provides better surgical view and workspace compared to the transsylvian approach. However, the former is characterized by less accessible important anatomical landmarks, such as peri-insular sulci, limen insulae, and lateral lenticulostriate arteries. Furthermore, the approach requires dissection of the brain matter of the frontal and temporal lobes. Conclusion. Detailed knowledge of the surgical anatomy of the insular region enables correct intraoperative identification of the number of major anatomical landmarks (limen insulae, peri-insular sulci) and facilitates the choice of the proper surgical approach.

Keywords: insular cortex, lenticulostriate arteries, transsylvian and transcortical approaches.

Approach to the insular cortex is one of the most common neurosurgical manipulations, which, along with the insula itself, opens M1 and M2 segments of the middle cerebral artery. The insula can be reached both through the Sylvian fissure and transcortical approach by removing one operculum covering the insula.

Currently, there is no consensus among the neurosurgeons regarding the optimal approach to the insula. Two methodological schools can be conventionally distinguished. The first school prefers transsylvian approach with wide dissection of the Sylvian fissure and without dissection of adjacent opercular area [1]. Adherents of the second one use the transcortical approach through the functionally insignificant opercular area [2, 3]. Both approaches require the detailed knowledge of the morphology of the insula, surrounding opercula, and vessels.

Material and Methods

The study was conducted on 18 anatomical specimens (9 left and 9 right hemispheres) of the brain of adults aged 21 to 79 years, whose death was not caused by intracranial pathology. After isolation of the brain from the skull cavity, catheters were placed to the lumens of the internal carotid arteries to the bifurcation level. Further, the arterial system of the brain was thoroughly washed with saline, followed by injection of the red-colored latex (2—3 ml) [4]. Thereafter, the catheters were removed from the lumen of blood vessels and the vessels were ligated. The preparation was immersed to the fixing liquid (96% alcohol and glycerol in a ratio of 4:1) for 3 days. Then microdissection of the Sylvian fissure was conducted using OPTON OPM6-SDFC-XY surgical microscope (with 4—10-fold magnification) in the following sequence: dissection of the superficial portion of the Sylvian fissure, dissection of the deep portion of the Sylvian fissure located under the temporal operculum, dissection of the deep portion of the Sylvian fissure located under the frontal and parietal opercula. The most important surgical landmarks were then explored, including the limen insulae, lenticulostriate arteries, peri-insular sulci, M3 and M2 segments of the middle cerebral artery, and insular gyri. The final step included the morphological study of the insular opercula (the size of the opercula and comparing their anatomy at the various portions of the insula), simulation of the transcortical approach by removing parts of the opercula covering 5 areas of the insula, and measuring the size of the peri-insular sulci.

Results

Sylvian fissure

Sylvian fissure is the most important anatomical landmark on the lateral and basal surfaces of the brain located between the frontal, temporal, and parietal lobes. Sylvian fissure includes basal (proximal) and lateral (distal) segments and each of them in turn consists of deep and superficial parts.

The boundary between the basal and lateral segments lies at the anterior Sylvian point (located at the triangular
Part of the inferior frontal gyrus), the place where the basal surface of the hemisphere turns into the lateral one.

The surface of the Sylvian fissure consists of three main sulci (Fig. 1), which are represented by three branches in the lateral segment: horizontal, ascending, and posterior ones. All three sulci begin at the anterior Sylvian point. The posterior sulcus runs in the distal direction between the frontal and parietal lobes at the top and the temporal lobe at the bottom. Horizontal and ascending sulci ascend forward horizontally and upward vertically, respectively, from the Sylvian point and divide the inferior frontal gyrus into three parts: the orbital, triangular, and opercular ones.

In the basal segment of the Sylvian fissure, the deepest part (sphenoidal) is formed by the proximal and medial portions of the superior temporal gyrus (planum polare), medially, and by lateral and posterior orbital gyri of the basal surface of the frontal lobe, laterally. This part of the Sylvian fissure extends from the limen insulae to the bifurcation of the internal carotid artery. It contains M1 segment of the middle cerebral artery, non-parenchymatous portion of lenticulostriate arteries, and deep Sylvian vein.

The deep portion of the distal segment of the Sylvian fissure is represented by the space formed between the contacting parts (opercula) of the frontal, parietal, temporal lobes and the lateral surface of the insula.

The inferior wall of the deep portion of the distal segment is formed by the temporal operculum (superior and medial surface of the superior temporal gyrus), which in turn consists of the following components (in anterior-posterior direction): planum polare, anterior Heschl gyrus (anterior transverse temporal gyrus), and planum temporale (Fig. 2).

Planum polare is the most proximal portion of the temporal operculum located between the Heschl gyrus posteriorly and the uncinate gyrus anteriorly. The anterior and posterior portions of the planum polare have different axes with respect to the sagittal plane. The posterior portion (from the Heschl gyrus to the precentral gyrus) is normally disposed to the sagittal plane, while the remaining anterior portion is deflected medially and makes an acute angle with this plane (Fig. 3). Planum polare covers the inferior surface of the anterior portion of the insula and limen insulae (see Fig. 2).

Planum temporale forms the distal portion of the temporal operculum and consists of the middle and posterior transverse temporal gyri (the plane of this portion of the temporal operculum is oriented perpendicular to the sagittal plane, i.e. more horizontally than anterior parts of this operculum (see Fig. 3b).

The anterior transverse temporal gyrus (Heschl gyrus) can be easily identified at the temporal operculum due to pronounced protrusion on its surface. It corresponds to the posterior lobe of the insula and the posterior third of the inferior peri-insular sulcus (see Fig. 2).

The anterior wall of the deep portion of the distal segment is formed by the frontal and parietal opercula (see Fig. 2). The frontal operculum includes the orbital, triangular, and opercular parts of the inferior frontal gyrus and the inferior part of the precentral gyrus. It should be noted that in 7 (38%) specimens, triangular portion was smaller compared to other parts of the inferior frontal gyrus (upward retraction), resulting in the increased width of the Sylvian fissure at this level.

Fig. 1. The branches of the superficial part of the Sylvian fissure.
Tegmental, triangular, and orbital part of the inferior frontal gyrus, side view.
The parietal operculum is formed by the inferior part of the postcentral gyrus and superior parts of the supramarginal gyrus.

The lateral wall of the deep portion of the distal segment of the Sylvian fissure is formed by the lateral surface of the insula.

M2 and M3 segments of the middle cerebral artery and the deep Sylvian vein are located at the deep part of the distal segment.

The insula

The insula is the only non-surface-exposed lobe of the brain. It is superiorly and inferiorly covered by parts of the frontal, parietal, and temporal lobes, which form 3 opercula, respectively.

Frontal and parietal opercula cover the anterior part of the lateral surface of the insula (the space formed in this way is called the superior insular-opercular fissure). Temporal operculum covers the inferior surface of the insula, which results in formation of the inferior insular-opercular fissure. Superior and inferior insular-opercular fissures are the constituents of the deep portion of the Sylvian fissure.

With removed opercular parts of the frontal, parietal, and temporal lobes, the insula looks pyramid-shaped (Fig. 4 and 5) with its tip directed towards the base of the brain. The insula is separated from the surrounding opercula by three sulci. The anterior peri-insular sulcus separates the anterior surface of the lobe from the frontal operculum. In this study, its length averaged 26 (24—33) mm. The superior sulcus defines the boundary of the lobe with the fronto-parietal operculum, its average length was 56 (52—63) mm. The inferior peri-insular sulcus separates the inferior surface of the insula from the temporal lobe. The average length of this sulcus was 47 (43—51) mm.

Sulci and gyri of the insula

Morphologic study has shown that the central sulcus of the insula was the deepest one and it was present in all specimens. Its length averaged 32 (24—42) mm. The direction and the angle of the central sulcus of the insula almost completely matched the direction of the Rolandic fissure in 14 cases, and in the remaining 4 cases, there was an antedisplacement of the lower end of Rolandic fissure by 3—4 mm with respect to the central sulcus of the insula.

The central sulcus of the insula divides its surface into 2 parts: larger anterior and smaller posterior one.

Fig. 2. Opercula of the brain and the insula, side view.

Fig. 3. Frontal sections at the anterior (a) and posterior (b) third of the insula.
A — the thickness of the opercula, B — the length of the antero-superior (a) and postero-superior (b) parts located under the frontal and parietal opercula. The arrow indicates the plane of the Sylvian fissure in its anterior and posterior third.
The anterior part consists of 3 short gyri: anterior, middle, and posterior (separated by the anterior and precentral sulci of the insula) ones, and also accessory and transverse gyri that are not always present. The posterior part is represented by the anterior and posterior long gyri and the postcentral sulcus, which is located in between (Fig. 6).

In 15 hemispheres, anterior, middle, and posterior short gyri were well defined, while the remaining 3 hemisphere were characterized by smaller middle short gyrus.

In all specimens, the posterior portion of the insula consisted of the anterior and posterior long gyri. However, in 13 hemispheres, the anterior long gyrus was larger than the posterior one, in 3 hemispheres both long gyri were similar, and in 2 specimens larger posterior gyrus was observed.

In 14 hemispheres, there was a transverse gyrus located in the anterior portion of the island, at the point of its junction with the posterior part of the fronto-basal region. Accessory gyrus of the insula located above the transverse one was found in 7 hemispheres.

In 2 hemispheres, there were additional gyri (which have no nomenclature names) located along the inferior peri-insular sulcus and separated from the known gyri by shallow sulci.

Apex of the insula, which is usually distinguished on the surface of the insula [5], is the most lateral portion of the lobe and thus closest to the cortical surface, which is usually located near to the middle short gyrus.

Limen insulae forms the antero-basal part of the lobe ("entrance" into the insula); it is the most important surgical landmark in the transsylvian approach to the insula. Limen insulae connects the temporal pole with the basal parts of the frontal lobe and is shaped like a semicircle. The anterior perforated substance is located immediately medial to the limen insulae.

Sulci and gyri of the insula have relatively constant relationship with the gyri of the opercula. The anterior short gyrus of the insula and the corresponding portion of the anterior peri-insular sulcus are projected onto the orbital part of the frontal operculum; middle and posterior short gyri correspond to the triangular and opercular parts. Posterior portions of the short posterior gyrus and the anterior part of the long anterior gyrus correspond to the precentral gyrus. Postcentral gyrus covers the remainder of the anterior long gyrus and anterior portions of the posterior long gyrus. The caudal part of the posterior long gyrus corresponds to the supramarginal gyrus. The inferior peri-insular sulcus approximately corresponds to the superior temporal sulcus. Limen insulae (and therefore the bifurcation of the middle cerebral artery) is located medial to the temporal operculum.

Thus, the anterior lobe of the insula is covered by orbital, triangular, and opercular parts of the inferior frontal gyrus, and inferior portion of the precentral gyrus from above and by planum polare of the temporal superior gyrus from below.

Posterior lobe is covered by the postcentral gyrus from the Sylvian fissure, the anterior portions of the

---

**Fig. 4.** The insula and peri-insular sulci; bottom and lateral view.

**Fig. 5.** The insula; side and bottom view.
supramarginal gyrus from above, and Heschl gyrus from below. All the insula is projected onto the lateral surface of the brain from the pars opercularis (horizontal branch of the Sylvian fissure) at the front to the anterior portions of the supramarginal gyrus from behind.

Thus, gyri and sulci of the frontal, temporal, and parietal opercula correspond to certain sulci and gyri of the insula, which can serve as a landmark during the transcortical approach to various portions of the insula.

The relation between the opercula of the brain and the insula

The distance between the anterior insular point (the intersection of the anterior and superior peri-insular sulci) and the lateral surface of the cortex at pars triangularis averaged 22 (18—26) mm, i.e. the width of the frontal operculum at this level was 22 mm (Fig. 7).

The length of the straight line connecting the posterior insular point (the intersection of the posterior and superior peri-insular sulci) with the point on the lateral surface of the supramarginal gyrus averaged 31 (28—35) mm (transverse dimension of the parietal operculum).

The thickness of the temporal operculum (the distance between the posterior insular point and the lateral surface of the cortex of the superior temporal gyrus) was 32 (27—35) mm.

Thus, there is an increase in the thickness of the opercula in the anterior-posterior direction, which complicates the approach to the posterior parts (long gyri) of the insula both through the transsylvian and transcortical approaches, increasing the depth of the surgical wound.

Measured distance between the limen insulae and the temporal pole averaged 20 (15—24) mm.

Frontal and parietal opercula covered on the average 22 (18—24) mm of the superior surface of the insula (the length of the operculum). The temporal operculum covered the inferior surface of the insula at a distance of 15 (11—18) mm. As a result, it was found that in the case of the transsylvian approach, the structures located under the frontal operculum are less accessible than those located under the temporal one (considering also extremely inconvenient supero-posterior attack angle). This is not the case with the transcortical approach and structures located under the frontal and temporal opercula are equally accessible.

The projections of the basal ganglia, lateral ventricle, and the internal capsule with respect to the insula

Claustrum, putamen, globus pallidus, anterior and posterior limb of the internal capsule, and thalamus are located medial to the insula.

Putamen and globus pallidus (lenticular nucleus) extend in the anterior-posterior direction from the level of the middle short gyrus of the insula to the anterior portions of the posterior long gyrus of the insula. Thus, the lenticular nucleus covers only the central part of the internal capsule from the insula-side, while its peripheral portions (anterior, superior, and posterior) lack this natural barrier (Fig. 8).

The foramen of Monro is located medial to the posterior short gyrus and therefore the genu of the internal capsule is projected to the level of the middle third of the insula (see Fig. 8). Thus, the pyramidal tract and thalamus are located under the posterior portion of the insula, i.e. the anterior and posterior long gyri.
All parts of the lateral ventricle are projected onto the insula. The anterior portions of the anterior horn of the lateral ventricles are projected onto the anterior peri-insular sulcus. The anterior peri-insular sulcus corresponds to the posterior parts of the anterior horn, body and the anterior part of the vestibule of the lateral ventricle. Posterior 2/3 of the inferior peri-insular sulcus is projected onto the inferior horn and the vestibule of the lateral ventricle.

**The blood supply to the insula**

The insula is mainly supplied with blood from multiple perforating arteries that run from the M2 segment of the middle cerebral artery (Fig. 9).

The arteries that form the M2 segment of middle cerebral artery run along the insular sulci, except for the superior peri-insular sulcus. The arteries cross this sulcus at the right angle (see Fig. 4, blue arrows).

In 17 hemispheres, M1 segment terminates with bifurcation at the limen insulae. In one hemisphere, there was trifurcation. In 15 hemispheres, the anterior stem supplied with blood the anterior, middle, and posterior short gyri, while in the remaining 3 hemispheres, perforating arteries both from the superior and inferior stem ran to the short gyrus. In 14 hemispheres, the anterior long gyrus was supplied by the inferior stem; in 3 hemispheres, it was supplied by both the superior and inferior stems; in one hemisphere, it was supplied by the middle stem. In all specimens, the posterior long gyrus was supplied with blood only by the inferior portion of the M2 segment. In two specimens, we also observed branches running from the M1 segment and supplying the limen insulae.

The results of our study have shown that in 5 (27%) hemispheres, perforating arteries of the M2 segment located at the superior portion of the posterior lobe have larger diameter compared to other perforating arteries (see Fig. 9). Only in two (11%) hemispheres these arteries reached the radiate crown.

**Lenticulostriate arteries**

Small-diameter branches of the middle cerebral artery that perforate the central and lateral parts of the anterior perforated substance are called lenticulostriate arteries. These arteries are usually subdivided into medial and lateral ones, depending of the place of branching from the middle cerebral artery.

Medial arteries supply blood to the head of the caudate nucleus, central medial portion of the putamen, the lateral segment of the globus pallidus, and partially the anterior limb of the internal capsule and anterosuperior portion of the posterior limb [6, 7] (Fig. 10a).

The lateral group of arteries supplies the superior part of the head of the caudate nucleus and the anterior limb of the internal capsule, a large portion of the putamen, part of the lateral segment of the globus pallidus, and the superior part of the genu and the posterior limb of the internal capsule with adjacent portion of the radiate crown [6, 7] (see Fig. 10b, Fig. 11).

Despite the fact that the number of the lenticulostriate arteries ranges 5 to 24 [8], occlusion of just one artery may cause the extensive infarction at the area of the basal ganglia and the internal capsule [9]. In the study of 18 hemispheres, the average number of arteries was 8 (3—20).

In 7 hemispheres, 1 to 3 perforating arteries branched from the medial third of M1 segment in the caudo-dorsolateral direction. In 18 specimens, 2 to 5 these arteries branched from the middle third in the caudo-dorsolateral direction.

Lateral lenticulostriate (LLS) arteries branched from the dorsal (or caudo-dorsal) part of the terminal third of M1 (Fig. 12) and were detected in all specimens. The average number of these arteries was 4. From the branching point, these arteries first run medially behind the M1 segment, then turn posteriorly, superiorly, and, before entering the anterior perforated substance, laterally.

In 5 (28%) hemispheres, LLS arteries branched from the M2 segment of the middle cerebral of artery in the immediate vicinity of the bifurcation (see Fig. 12a).

It is important to note that in 7 (38%) hemispheres, lateral lenticulostriate arteries branched from the M1 segment as a single stem, which then split into separate branches.

The average distance between the entrance point of the most lateral lenticulostriate artery to the anterior perforated substance and the limen insulae was 16 mm (see Fig. 12b), and the average length of the lateral lenticulostriate arteries from the place of origin on the M1 segment to the entrance to the anterior perforated substance was 4 mm.

**The anatomical boundaries of resection of insular gliomas**

The knowledge of the anatomical features of the insula and possible anatomical boundaries of resection...
Fig. 8. a — horizontal section at the level of the fornico-commissure; top view. Red arrows indicate the portions of the internal capsule that are not protected by the putamen; blue arrow — the area of the internal capsule, covered by the putamen; b — insular gyri.
Fig. 9. a — the insula and M2 and M3 segments of the middle cerebral artery. Blue arrows indicate numerous small-diameter perforating (insular) arteries; white arrow — long perforating artery in the postero-superior part of the insula; b — long perforating vessel running from the M2 segment of the middle cerebral artery (white arrow) in the postero-superior part of the insula.

(mainly medial) is extremely important in surgical treatment of diffusely growing gliomas of the insula.

The following anatomical structures are, in our opinion, possible boundaries for resection of glial tumors of the insula: supero-medial boundary — radiate crown (intraoperative landmark — anterior peri-insular sulcus) infero-medial boundary — retrolenticular part of the internal capsule; postero-medial — posterior limb of the internal capsule (no intraoperative landmarks); centro-medial — the extreme and external capsule or the subcortical nuclei (clastrum/putamen) depending on the degree of spread of the tumor in the medial indirection (intraoperative landmark — the emergence of the gray/beige substance of the basal ganglia), antero-medial — the anterior part of the anterior limb of the internal capsule (no intraoperative landmarks); antero-basal — the anterior perforated substance (intraoperative landmarks — the limen insulae, M1 segment of the middle cerebral artery, and the most distal lenticulostriate artery).

**Approach simulation**

Transcortical (9 hemispheres) and transsylvian (another 9 hemispheres) approaches were simulated.
During simulations of the transsylvian approach, the following steps were performed: dissection of the surface portion of the Sylvian fissure, dissection of the deep portion of the Sylvian fissure located under the temporal operculum, dissection of the deep portion of the Sylvian fissure located under the frontal and parietal operculum.

During simulations of the transcortical approach, we removed opercular parts located above one of the 5 zones (Fig. 13): limen insulae, the superior portions of the anterior lobe (under the frontal operculum), the inferior portions of the anterior lobe (under the temporal operculum), the superior portions of the posterior lobe (under the parietal operculum), and inferior portions of the posterior lobe (under the temporal operculum).

Discussion

Despite the practical significance (up to 25% of all low-grade gliomas and up to 10% of all high-grade gliomas are located in the insula [10]) and functional complexity (the insula is surrounded by Broca and Wernicke speech centers arranged around the Sylvian fissure, primary motor and sensory cortex of the facial area, as well as pathways connecting these areas) of the insula, only several publications devoted to the study of the anatomy of this area of the brain are currently available [5, 8, 9, 11, 14]. Moreover, it has currently been shown that the insula plays a key role in many processes, from viscerosensory processes and perception of pain to the motivational processes, cognitive control of emotions, and speech [15—18]. T. Wager said that the insula is a key connecting thinking and affective sphere, while A. Craig believed that the anterior part of the insula that gets rich interoception and has strong connections with limbic structures is responsible for consciousness [19].

In our study, we focused on morphological features of the insular gyri and opercula, the specifics of the vascular system of the insular region from the viewpoint of two basic approaches used to reach the insula: transsylvian and transcortical.

In the classical works, the insula is described as a pyramidal-shaped fifth lobe of the brain bounded from the surrounding frontal, parietal, and temporal lobes by the peri-insular sulci. Most authors [5, 11, 14] distinguish the anterior, superior, and posterior peri-insular sulci. A somewhat different view is presented in A. Afif et al. [13], where the insula is represented as a trapezoid, and the authors describe 4 peri-insular sulci: the anterior, superior, posterior, and inferior ones. When studying our anatomical material, we adhered to the description of the anterior, superior, and posterior peri-insular sulci.

It is known that the insula is supplied with blood by multiple perforating arteries branching from the vessels of M2 segment of the middle cerebral artery that lie on the insula. However, there is an important practical question, whether they can be coagulated during the

Fig. 10. Pathway of the medial (a) and lateral (b) lenticulostriate arteries. Frontal section; front view.
resection of the tumor? How deep these arteries extend medially and where is the margin of the area they supply.

Some authors report data on the presence of long perforating arteries having different diameter that branch from the M2 segment and occur predominantly in the posterior portion of the insula.

Prior to our study, these arteries were described only in three works and G. Varnavas et al. [14] was the first who observed large-diameter perforating arteries in the superior portion of the posterior lobe of the insula in a quarter of hemispheres under study. Supply area of these arteries was not specified.

Tanriover et al. [11] described the large-diameter perforating arteries not only at the supero-posterior portion of the insula, but also at the inferior regions of the posterior lobe.

Ture et al. [8] have shown that approximately 85—90% of the insular (branching from the M2 segment) arteries are short and supply with blood only insular cortex and extreme capsule, 10% of arteries have an average length and reach the claustrum and external capsule, and 3—5% of arteries are long (they can be found in the posterior lobe of the island) and supply the radiate crown. Injury to the latter during the resection of insular tumors can lead to hemiparesis.

When examining our material, we observed large-diameter perforating arteries of M2 segment only in the superior portions of the posterior long gyri. They supplied the radiate crown only in 2 (11%) hemispheres. In all other cases, they branched not further than the lateral part of the putamen. Consequently, the external capsule is the medial boundary of blood supply area of insular arteries, except for the supero-posterior parts of the insula, where in few cases perforating artery reach the radiate crown.

Since gliomas of the insula are supplied with blood by perforating arteries of the M2 segment, one of the stages of tumor resection [1] is its devascularization by coagulation of perforating arteries of M2. However, given the results of anatomical studies, we suggest that, in the posterior portions of the insula, this stage of approach (if a large perforating vessel is coagulated) may lead to ischemic damage to the radiate crown and, as a consequence, neurological deficit.

Preservation of the lenticulostriate arteries is one of the greatest challenges of surgery of the insula and damage to these arteries is considered to be the main cause of persistent neurological deficit [1, 20]. In this regard, the most lateral lenticulostriate artery becomes important as the intraoperative landmark [21], which is available only in transsylvian approach and allows determining the lateral margin of the anterior perforated

---

**Fig. 11. Schematic representation of the arterial system of the insular region.**

1 — long perforating artery of the M2 segment of middle cerebral artery; 2 — medial lenticulostriate arteries; 3 — lateral lenticulostriate arteries; 4 — short perforating arteries of the M2 segment of the middle cerebral artery.

**Fig. 12.** a — lateral lenticulostriate arteries branch from the M1 and M2 segments of the middle cerebral artery; b — lateral lenticulostriate arteries branch only from the M1 segment of the middle cerebral artery.
Figure 13. Parts of the insular cortex are shown in different colors. 1 — antero-superior; 2 — postero-superior; 3 — postero-inferior; 4 — antero-inferior; 5 — limen insulae.

The insula is characterized by the lack of surface exposure of its cortex, which complicates direct surgical approach. The insula is covered by opercula, i.e., portions of the temporal, frontal, and parietal lobes, located above and below the insula. In the literature, there are differences in the notation of insular opercula. Some authors believe that there are three opercula: frontal, parietal, and temporal ones [11] (or fronto-orbital, fronto-parietal, and temporal [5]), while others describe only two opercula: fronto-parietal and temporal [12]. In our view, the notation of the frontal, parietal, and temporal opercula is optimal, since in this case, the names and boundaries of the opercula match the lobes, in which they are located.

However, the variants of notation of the opercula have no fundamental (practical) value, as opposed to the features of their structure in their anterior/posterior and superior/inferior portions, which determine different accessibility of the regions of the insula in the transcortical and transsylvian approaches.

In our view, the insula can be naturally divided into several sections (see Fig. 14). The central sulcus divides the insula into the anterior and posterior lobes. In both of them, the superior part is located under the frontal/parietal operculum and the inferior part is located under the temporal operculum. Thus, the insula is divided into four sections: antero-superior, antero-inferior, postero-superior, and postero-inferior ones. We also believe that it is appropriate to distinguish the limen insulae in the antero-inferior section due to its anatomical proximity to the anterior perforated substance.

The thickness of the opercula at the anterior lobe of the insula is smaller than that at the posterior one, and the height of the frontal and parietal opercula is larger than that of the temporal one. Therefore, the surgical wound is deeper in the posterior parts of the insula compared to that in the anterior parts.

In addition, the axis of the planum polare, which covers the antero-inferior section of the island, in contrast to all other opercula, is oriented at an acute angle to the sagittal plane and declined laterally (see Fig. 4). Together with upward retraction of the triangular part, this increases the free space of the Sylvian fissure at this level and facilitates retraction during the transsylvian approach to the antero-inferior portions of the insula.

Therefore, when modeling the transsylvian approach on the anatomical preparations with allowance for the morphology of the cerebral opercula covering the insula, we came to the conclusion that inferior parts of the lobe are more accessible than the superior ones (due to extremely inconvenient supero-posterior attack angle and greater height of the frontal and parietal opercula compared to the temporal one).

The accessibility of the antero-superior and postero-superior parts is also different. Despite the smaller depth of the wound during the approach to the antero-superior parts of the insula compared to that during the approach to the postero-inferior parts (see Fig. 3 and 7), the distance to the superior peri-insular sulcus (the length of the antero-superior and postero-superior parts located under the frontal and parietal opercula (see Fig. 3, distance B) is larger in the antero-superior part of the lobe, which leads to equally inaccessible antero-superior and postero-superior parts during the transsylvian approach. Smaller thickness of the opercula in the antero-superior portions is compensated by the longer distance to the superior peri-insular sulcus (see Fig. 3, distance B), which makes this part the least accessible during the transsylvian approach.

Therefore, the inferior areas of the insula (including the limen insulae) are the most accessible, while the superior areas are the least accessible ones during the transsylvian approach. For this reason, in the cases when a tumor is located in these areas of the insula, transcortical approach may be recommended, since, unlike the transsylvian approach, it does not require significant retraction of the medulla and provides greater surgical corridor.

When simulating the transcortical approach, the greater depth of the surgical wound in the posterior regions compared to the anterior ones was the only difference in the accessibility of the parts of the insula.
Since the transcortical approach includes resection of the part of the operculum located above the tumorous region of the insula, the attack angle (and therefore the accessibility) to the superior and inferior portions of the lobe is similar, unlike the transsylvian approach.

Regardless of the part of the insula, the transcortical approach provides greater surgical visibility and workspace compared to the transsylvian one. However, in cases when a tumor is located at the limen insulae, it does not provide a reliable proximal control of the lenticulostriate arteries. For this reason, transsylvian approach may be advisable for localization of tumor in this area.

Summary

Detailed knowledge of the surgical anatomy of the insula enables the correct intraoperative identification of a number of major anatomical landmarks (the limen insulae, peri-insular sulci, and the most distal LLS-artery) and facilitates the correct selection of the surgical approach.

REFERENCES


Commentary

This study deals with surgical anatomy of the insular region of the brain from the perspective of the transsylvian and transcortical approaches to the insula during resection of the gli al tumors of this area. This in an academic-style study. The study was conducted on 15 anatomical brain preparations with vessels filled with colored latex according to the method adopted at the Burdenko Neurosurgical Institute. The work mainly focuses on the morphological features of the insular gyri and opercula, the specifics of the vascular system of the insular region when conducting two commonly used approaches, transsylvian and transcortical ones. When simulating these approaches, the authors concluded that in the transsylvian approach, the inferior areas of the insula, including the threshold, are the most accessible ones. When the tumor is located in the superior regions of the insula, the transcortical approach is more appropriate, as it does not require significant retraction of the medulla and provides greater surgical visibility. The work is illustrated with color images of the anatomical structures of the insular region.

The article is of great interest for neurosurgeons and can be recommended for publication in the neurosurgical journal.

V.A. Lazarev (Moscow, Russia)
The Use of Frameless Navigation During Endoscopic Interventions in Children with Multilocular Hydrocephalus

S.A. KIM1, G.V. LETYAGIN1, V.E. DANILIN1, A.A. SYSOEVA1, D.A. RZAEV1, G.I. MOYSAK1,2

1Federal Neurosurgical Center, Novosibirsk, Russia; 2Novosibirsk State University, Novosibirsk, Russia

Introduction. The use of the endoscopic technique largely improves treatment outcomes in patients with multilocular hydrocephalus. However, impaired anatomy and the lack of usual landmarks often cause problems in planning and intraoperative identification of changed structures. The use of frameless navigation during endoscopic interventions can significantly facilitate surgeon tasks and increases the efficacy of surgery. During surgery, the neuronavigation system visualizes a rigid endoscope that interconnects separated ventricles and cysts. Surgery can be completed with guiding a stent through an operating channel of the endoscope and implanting a shunt system. Material and methods. Ten children underwent 11 endoscopic interventions using frameless intraoperative navigation at our clinic in 2013–2014. The number of surgically interconnected compartments ranged from 3 to 5. Simultaneous placement of a shunt system was performed in 8 of 11 interventions. Results. Clinical improvement as a result of the operation was achieved in all children. 2 patients underwent re-operations 5 months and 1 year after endoscopic intervention. Conclusion. Thus, the use of frameless navigation during endoscopic interventions makes their implementation most efficient and safe for the patient.

Keywords: multilocular hydrocephalus, neuroendoscopy in children, frameless navigation.
and ring-shaped headrests and gel pads that prevent excessive pressure on the soft tissues.

Prior to the surgery all children underwent thinsliced MRI of the brain with pre–installed markers on the head. The data obtained were transferred to a neuronavigation station, which was used to create a 3D model of the patient’s head. Preoperative planning included identification of the best entry point and determination of trajectory for perforation of multiple cysts based on the MRI data, as well as calculation of the required length and position of the catheter.

After anesthetic management and fixation of the head with a Mayfield clamp, the patient’s head was registered in the navigation system. Active pointer was used for mapping the scalp in accordance with the previously planned approach. The surgical field was then processed and covered with sterile linen and the rigid endoscope was registered in the neuronavigation system. For this, reflective spheres were firmly attached to the endoscope in order to enable the navigation system to track 3D position of the working part of the tool relative to the constructed images in real time.

The most common approach was the one through enlarged lateral ventricles (8 patients). The cyst was then visualized using the previously planned trajectory and its wall was perforated. The endoscope was inserted into the cavity of the cyst through the resulting opening and fenestration of the anterior wall of the cyst was performed under the control of the navigation system. Depending on the location of the cyst, it was anastomosed to the isolated posterior horn of the ipsilateral lateral ventricle (2 cases), cavity of the contralateral lateral ventricle (5) or isolated fourth ventricle (3). In case of additional isolated cavities, the endoscope was pulled back from the cavity of the perforated cysts into the lateral ventricle. Then the trajectory was modified and intrahemispheric cyst was identified under visual and navigational control. Its perforation was performed in the same manner and anastomosis with the contralateral lateral ventricle was created (1 case). In one child the cyst of the quadrigeminal cistern was accessed through the cavity of the cyst in the lateral ventricle. Both of its walls were perforated and a flexible endoscope was used to create anastomosis with the cyst on the craniovertebral level. In 2 patients the approach was performed directly through the cyst cavity. In the first case, the areas adjacent to both lateral ventricles were identified in the cavity of the interhemispheric cyst and anastomosis was created in those places. In the second case, the cyst was perforated in places of its contact with cyst in the opposite hemisphere and the isolated fourth ventricle. In 2 cases, ultrasound scanning through the anterior fontanelle was used for additional intraoperative monitoring. In the final stage of the surgery a silicone stent with additional lateral holes was guided through the working channel of the endoscope to prevent re-occlusion. The distal end of the catheter was placed in the cavity of the fourth ventricle (3 patients), the contralateral lateral ventricle (3) or in the posterior horn of the ipsilateral lateral ventricle (1). Next, the catheter was guided through the cavity of the cyst into the lateral ven-

Table 1. Characteristic of the surgeries

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Gender</th>
<th>Number of interconnected compartments</th>
<th>Stent implantation</th>
<th>VP shunt implantation</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sh.</td>
<td>1 year</td>
<td>F</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td>Mantle-like subdural hematoma</td>
</tr>
<tr>
<td>O.</td>
<td>5 months</td>
<td>M</td>
<td>5</td>
<td>+</td>
<td>+</td>
<td>Stent displacement</td>
</tr>
<tr>
<td>V.</td>
<td>5 years</td>
<td>M</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Z.</td>
<td>3 years</td>
<td>F</td>
<td>3</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>K.</td>
<td>11 months</td>
<td>M</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>B.</td>
<td>7 months</td>
<td>M</td>
<td>4</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>P.</td>
<td>7 months</td>
<td>M</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>P.</td>
<td>1 year 7 months</td>
<td>M</td>
<td>3</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>S.</td>
<td>1 month</td>
<td>F</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>M.</td>
<td>1 month</td>
<td>M</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>L.</td>
<td>10 months</td>
<td>M</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Dynamics of clinical manifestations in the post-operative period

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Incidence in the group prior to the surgery</th>
<th>Dynamics after the surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No dynamics</td>
</tr>
<tr>
<td>Pathological increase of head circumference</td>
<td>8 (72.7%)</td>
<td>—</td>
</tr>
<tr>
<td>Oculomotor disorders</td>
<td>9 (81.8%)</td>
<td>—</td>
</tr>
<tr>
<td>Vomiting</td>
<td>4 (36.4%)</td>
<td>—</td>
</tr>
<tr>
<td>Bulbar disorders</td>
<td>4 (36.4%)</td>
<td>—</td>
</tr>
<tr>
<td>Respiratory disorders</td>
<td>1 (9%)</td>
<td>—</td>
</tr>
<tr>
<td>Seizures</td>
<td>7 (63.6%)</td>
<td>—</td>
</tr>
<tr>
<td>Developmental impairment</td>
<td>10 (90.9%)</td>
<td>—</td>
</tr>
</tbody>
</table>
tricle towards the burr hole. In one case, the stent was fixed with ligature to the dura mater. In 1 case a standard VP shunt installation was performed after the conclusion of the endoscopic stage of the surgery. In 6 patients the stent was used as ventricular catheter for the shunt system that has been installed after the conclusion of the endoscopic stage of the surgery.

**Results**

After the surgery all patients underwent thorough examination of their neurological status, assessment of blood pressure, heart rate, respiratory rate, level of consciousness, dynamics of seizures, cerebral and focal neurological symptoms. All patients also underwent spirometry CT of the brain on Day 1—2 days after the surgery.

The number of surgically interconnected compartments ranged from 3 to 5. Simultaneous placement of a shunt system was performed in 8 out of 11 interventions. Characteristics of the surgeries are presented in Table 1.

Complications were observed in 2 (18.2%) cases. After the surgery one child was diagnosed with small mantle-like subdural hematoma on the side of the intervention, which did not cause significant mass effect and did not require additional surgery. In another child, distal end of the stent was displaced from the cavity of the cyst into the lateral ventricle, which did not lead to disruption of drainage through a shunt system and also did not require re-surgery. After the surgery, all children displayed regression of clinical manifestations and they were discharged from the hospital (Table 2). There were no deaths in this group of patients.

The average duration of the postoperative hospital stay was 9 days. Five months after the surgery 1 child developed shunt infection and the VP shunt was removed. Once cerebrospinal fluid had been cleared up, the shunt system was reinstalled.

In 1 child a recurrence of the cyst of the opposite lateral ventricle one year after the intervention caused significant deformation of the liquor system and subsequent migration of the stent accompanied by the VP shunt malfunction. In this case, endoscopic intervention was repeated, the cyst was anastomosed to the lateral ventricles and the shunt system was replaced.

**Clinical case 1**

Baby B., 7 months old, was admitted based on parents’ complaints of increased size of the head, vomiting, refusal to eat, fontanelle tension, and respiratory failure.

The medical history revealed that the child has been sick since birth. The birth took place at week 33—34. Critical condition at birth, Apgar score 7/7 points, mechanical ventilation for 3 days starting with Day 2. The child experienced seizures in the intensive care unit and was prescribed 75 mg of Depakine 2 times a day. On Day 15 the child was transferred from the maternity ward to the department of newborns pathology with a diagnosis of purulent meningoencephalitis, ventriculitis of unknown etiology, II degree IVH, complicated by decompenated obstructive hydrocephalus and the long-term antibiotic therapy with Depakine, Diacarb was prescribed. The child was discharged at the age of 4 months and subsequently treated on an outpatient basis with Depakine and Diacarb. At the age of 5 months he underwent inpatient treatment at the neurosurgery department of the local hospital and a VP shunt was installed. One month later the shunt was revised due to malfunction; the VP shunt was removed and external drainage was installed. After the removal of the drainage the child was discharged with a recommendation to consult a federal clinic. The condition of the child deteriorated within the last 3 days before the admission: reduced motor activity, decreased appetite, complete refusal to feed, fountaining vomit, and decrease in breathing during the day. The child was immediately hospitalized to the pediatric department.

Critical condition upon the admission; the child was conscious, but adynamic. Only sluggish motor response to examination and pain stimuli. Bradypnea up to 12 per 1 min with 10—15 s periods of apnea. Hydrocephalic skull with pronounced predominance of cranial skull over facial. Head circumference 53 cm, anterior fontanelle 6 × 6 cm, tense. Pronounced subcutaneous venous network on the head. Equal eye slits. Exotropia. Bilateral Graefe symptom. Round and equal pupils. Photoreaction was preserved. Symmetrical face. Pseudobulbaralsy. Arm tendon reflexes were present and equal. Knee-jerk reflexes were equal and enhanced. Central tetraparesis, 3 points.

MRI of the brain revealed multilocular obstructive hydrocephalus with isolated cysts in the third and fourth ventricles (Fig. 1).

Emergency neuronavigated endoscopic intervention was performed, which resulted in the lateral ventricles of the brain anastomosed to the cysts in the third and fourth ventricles. A silicone stent was guided through the openings formed in the third and fourth ventricles and used as a ventricular catheter for a VP shunt (Fig. 2).

Positive trend was observed in the postoperative period: regress of hypertension-hydrocephalic syndrome, improvement of general condition, normalization of respiratory function, transfer from tube to independent feeding with progressive increase in intake, regress of oculomotor disorders, emergence of emotional reactions. The child was discharged in a satisfactory condition.

**Clinical case 2**

The child Sh., 1 year old, was admitted based on parents’ complaints of increased size of the head, anxiety, prolonged monotonous cries, refusal to eat, choking on swallowing, seizures.

The medical history revealed that the child was operated on at the age of 1.5 months in a clinic in Novosibirsk for the post-hemorrhagic obstructive hydrocephalus and...
Fig. 1. Intraoperative screenshots of the navigation station. The purple dotted line denotes the planned trajectory. The green dotted line indicates the position of the endoscope at the current time. Green lines crosshair corresponds to the tip of the endoscope.

a — the approach was performed through the anterior horn of the right lateral ventricle; the wall of the right lateral ventricle cysts was perforated and the endoscope was inserted in its cavity; b — after passing through the right lateral ventricle cyst, the endoscope was guided subtentorially and the posterior fossa cyst was fenestrated.
a VP shunt was installed. The patient was discharged under the supervision of a neurologist. Two months later she was re-operated due to shunt infection, the VP shunt was removed and external ventricular drainage was installed. Once the CSF had been cleared up, a VP shunt was reinstalled. The child was discharged with improvement under the supervision of a neurologist. Two months later the shunt infection re-emerged and the VP shunt was removed again and the external drainage was installed. Prolonged external drainage was conducted, and antibacterial therapy was initiated (Ceftriaxonum, Amikacinum, Meronem).

The MRI results revealed polycystic brain damage with isolated cysts of right and left hemispheres, fourth ventricle (Fig. 3).

The child underwent endoscopic intervention under the control of intraoperative frameless navigation, which established communication between the cysts in the left and right hemispheres and the cyst in the fourth ventricle. Simultaneously, a shunt system with the drainage of cysts of fourth ventricle and cerebral hemispheres has been installed (Fig. 4).

Postoperatively, the child displayed positive dynamics: regress of the hypertensive syndrome, improvement of the general condition, normalization of the respiratory function, transfer from the tube to independent feeding with progressive increase in intake, regress of the oculo-motor disturbances, emergence of the emotional reactions. The child was discharged in a satisfactory condition.

Discussion

To date, hydrocephalus remains to be the most common pathology faced by neurosurgeons worldwide. The most challenging subgroup within it includes patients with different types of multilocular hydrocephalus, involving separation of the ventricular system into multiple isolated compartments. This issue can only be resolved by surgical methods. However, there is still no consensus on what type of surgery is the most effective and safe method of choice for this pathology [2, 6—14].

The most common method, which involves installation of a shunt system, can often require implantation of several shunts and multiple revisions [14—17]. Furthermore, mortality rate due to postoperative complications can reach 54% [4].

Another treatment option is to perform stereotactic aspiration of the cysts and establish communication between the cavities. However, the incidence of cysts recurrence for this procedure remains to be high, reaching 80%, due to the inability to perform stereotactic devascularization of the cyst or create a sufficiently large opening in the wall of the cyst [17, 18].

It is also possible to perform a microsurgical dissection of the cyst using transcallosal or transcortical approach [19, 20]. The advantage of the microsurgical method is the possibility to achieve the most adequate hemostasis during the dissection under direct visual control with the help of bipolar coagulation and hemostatic materials. High magnification improves visualization and facilitates the creation of multiple connections over suf-
ficient distance. However, open surgeries are not without drawbacks. Transcallosal approach requires a lot of experience and relevant skills, and carries inherent risk of thrombosis of the sagittal sinus, accidental damage to pericallosal artery, venous infarction at crossing of the bridging veins and cognitive impairment due to damage to the corpus callosum [21].

The use of transcortical approach could lead to the development of epileptic seizures in the postoperative period, subdural accumulation of CSF against the background of the marked thinning of the cerebral mantle in case of hydrocephalus [4]. Shrinkage of the ventricles' walls due to CSF outflow during decompression of cysts is also possible [22]. Furthermore, additional craniotomy may be required in case of the fourth ventricle cysts or a need to install a shunt.

In our opinion, neuroendoscopic interventions are the most promising in this category of patients, as they allow anastomosing the cavities by fenestration of their walls from a single burr hole [2, 11, 23, 24]. In some cases, endoscopy allows patients to have previously implanted shunt system removed or saves them from having it installed [2, 11, 25]. However, impaired anatomy and the lack of usual landmarks often cause problems in planning and intraoperative identification of changed structures. The use of frameless navigation during endoscopic interventions can significantly facilitate surgeon tasks and increases the efficacy of surgery [26—28]. The combined use of endoscopic techniques and frameless navigation virtually eliminates the need to use several approaches to anastomose multiple cavities in the same patient, thus allowing prevention of hydrocephalus progression in a single intervention. All patients in this group improved after the surgery, which confirms rather high efficiency of this type of interventions. Furthermore, the use of intraoperative navigational control minimizes the risk of damage to critical structures such as large vessels, functionally significant areas and stem sections of the brain.

Neuroendoscopic intervention may be accompanied by complications such as intraventricular hemorrhage,
Fig. 4. Case 2: MRI of the child’s brain before the surgery.
Isolated cysts of the right and left hemispheres of the fourth ventricle; c, direction of the endoscope during perforation of the posterior wall of the cyst of the right hemisphere, which separates it from the fourth ventricle; d, after anastomosis with the fourth ventricle the endoscope was returned to the cyst cavity in the right hemisphere and the trajectory was changed towards the cyst of the left hemisphere (arrow).

Fig. 5. Case 2 (continued).
a — intraoperative photograph. The endoscope is located in the cavity of the cyst of the right hemisphere, perforated posterior wall of the cyst is visible, through which silicone catheter is guided into the fourth ventricle; b — postoperative reconstruction of the CT scan of the brain. The stent, responsible for the drainage of the fourth ventricle drainage and the cyst is visible.
ventriculitis, nerve damage to surrounding structures and liquorrahea. In the study by N. El-Ghandour [11] 2 (8%) out of the 24 children with multilocular hydrocephalus who were operated on endoscopically had slight intraoperative hemorrhage which was stopped within minutes and did not require interruption of the surgery. Postoperatively, none of these patients displayed additional neurological symptoms and none of them required craniotomy. In the postoperative period liquorrahea was observed in 2 (8%) patients, but resolved within 3 days [11]. In another group of 34 patients with complicated hydrocephalus who underwent endoscopic intervention, there was 1 (3%) case of postoperative liquorrahea and 1 (3%) patient developed neuroinfection [23]. Complications in 2 (18.2%) of our patients did not require additional intervention and generally did not affect the overall positive outcome of the treatment.

**Conclusion**

Endoscopic surgery is the treatment of choice for the patients with multilocular hydrocephalus. The use of frameless navigation during endoscopic interventions makes their implementation most efficient and safe for the patient. A combination of minimally invasive endoscopic approach and neuronavigation facilitates preoperative planning and intraoperative identification of targets in case of modified anatomy and absence of natural landmarks. Endoscopic stenting of the established communications virtually guarantees an adequate positioning of the catheter and prevents the recurrence of occlusion.

The purpose of surgery is instantaneous drainage of the maximum possible number of cavities, using minimal number of proximal catheters and, if possible, only one shunts system or in some cases no shunting at all.

**There is no conflict of interest.**

**Author Contributions:**

Concept and design of the study — S.A., G.V., D.A. Collection and processing of the data — S.A., A.A. Statistical analysis — V.E. Preparation of the manuscript — S.A. Editing — D.A., G.I.

**REFERENCES**

Commentary

The work is dedicated to the issue of surgical treatment of obstructive multilocular hydrocephalus. This type of the disease is quite common, especially in children with hydrocephalus of post-hemorrhagic and post-meningitis etiology. Complex systems with connectors and multiple ventricular catheters have to be used for shunting due to septation and isolation of ventricular with multiple intraventricular and periventricular CSF cysts. Not all CSF cavities can be connected with efficient and reliably functioning shunt, though.

The authors employed endoscopic fenestration of cyst walls. It is a challenging task, because in these patients the anatomy of the brain ventricles and cisterns is deformed and altered, therefore familiar landmarks are hard to recognize or simply hidden and inaccessible. On the other hand, since openings in the walls of these cysts and intraventricular membranes typically close up, the purpose of the surgery, in addition to their fenestration, is usually installation of tubular stents, i.e. silicone catheters. Multiple additional perforations in a catheter securely connect all separated compartments and it can be fixed to the periosteum or connected to a valve of a shunt system, radically simplifying it. It is very difficult to calculate the trajectory along which the endoscope is to be guided and even more so to implement it without stereotactics. The authors used frameless navigation and, in some cases, when required, alternated between rigid tool, a flexible fiberendoscope and ultrasound.

At the first glance, the experience gained by the authors is not huge: 10 patients only. Nevertheless, they have convincingly demonstrated how important it is to simplify the configuration of the shunt system and how to implement it both safely and effectively. The paper is good, and will be of interest to readers.

A. Melikyan (Moscow, Russia)
Spiral CT perfusion in the Diagnosis of Sellar and Parasellar Tumors


Burdenko Neurosurgical Institute, Moscow, Russia

The study focuses on the use of minimally invasive method of spiral CT perfusion for the differential diagnosis of sellar and parasellar tumors. Given a wide differential diagnostic range of tumors occurring in this area, tumor perfusion values were used as an auxiliary diagnostic criterion. Material and methods. The study analyzed the outcomes in 115 patients with various neoplasms at the chiasm-sellar region, who later underwent surgery or biopsy for histological verification of the diagnosis. Results. The statistically significant differences in the values of hemodynamic parameters were obtained for certain groups of tumors (p<0.05), which enables assessing the histologic type of most tumors with high confidence. Conclusion. These findings demonstrated that spiral CT perfusion is a highly informative method of the preoperative differential diagnosis of these tumors. In this study, the sensitivity and specificity of spiral CT perfusion were 100% and 81.2%, respectively.

Keywords: spiral CT perfusion, brain tumors, chiasm-sellar region.

According to different authors, the tumors of the chiasm-sellar region (CSR) account for 15—18% of all brain tumors in adults. The peak incidence falls on the active working age (20—50 years). The CSR tumors represent a heterogeneous group of diseases that require different approaches to the choice of treatment strategy. In some cases, radical removal of a tumor is preferable, while in other cases, only biopsy followed by combined adjuvant treatment is possible. In some patients, follow-up, watchful waiting, and extensive differential diagnostic search are advisable.

Surgical treatment of patients with CSR tumors pose a serious problem to modern neurosurgery. As a rule, pathological involvement of major anatomical structures, such as carotid siphons and cavernous sinuses with cranial nerves extending through their walls, is diagnosed as early as during initial examination. Along with the deep location, this causes significant difficulties is the choice of the adequate surgical approach for radical resection of the tumor with minimal risk of intra- and postoperative complications [1—4].

It should be noted that CSR lesions include a wide range of pathological conditions, both neoplastic and non-neoplastic ones (for example, inflammation). Despite the fact that in most cases modern spiral computed tomography (SCT) and MRI scanners can visualize pathological changes in the CSR, the correct interpretation of the results is often a challenge for a neuroradiologist. First of all, this is due to the fact that the standard CT and MRI scan protocols only provide information on the structural changes in the CSR. Of course, differential diagnosis in neuroradiology is always conducted with allowance for the complex of data, including sex and age of a patient, as well as clinical and laboratory research. Thus, in children, the presence of the space-occupying mass in the CSR with petrification foci on CT, multicystic changes on MRI, and clinical signs of endocrine disorders first of all suggests craniopharyngioma. Enlarged anterior pituitary gland in adults is primarily about the pituitary adenoma. Nevertheless, in some cases, especially for small lesions in this region or, conversely, large space-occupying masses, when it is impossible to specify the primary growth characteristics and localization of the neoplasms, structural data are not sufficient to assess the true nature of the pathology.

For this reason, new techniques are used in the neurosurgical clinic, which enable identifying functional characteristics typical of a certain type of pathological tissue, regardless of the volume of the pathological focus. These methods are PET, SPECT, MRI perfusion, MR spectroscopy, and others. [5-10]. Each of these methods has certain limitations. Thus, PET and SPECT, which showed good results in the study of the metabolic activity of glial tumors, are still not enough available for extensive clinical use (small number of PET centers). Moreover, the high variability of available radiopharmaceuticals caused the need for clinical trials to assess their effectiveness and validate the results of studies. T2*-weight perfusion MRI, which is widely used to assess the hemodynamic changes in glial tumors, proved to be uninformative when assessing lesions at the skull base due to the emergence of artifacts coming from the bone structures. Furthermore, assessment of metabolic changes in tumors using MR spectroscopy is still rarely used in diagnostics of pathological processes located near massive bone bodies.

In our opinion, CT perfusion technique is the most promising for extensive use in the clinic at all stages of preparation for surgical or conservative treatment of CSR tumors. Advantages of this method include the abundance and availability of SCT scanners in many centers and regions of the Russian Federation, the high rate of the study, the possibility to obtain anatomical, structural, and pathophysiologic (hemodynamics) information simultaneously in a single procedure, and relatively low cost (compared to PET and SPECT). Compared to MR perfusion, CT method demonstrates higher resolution without spatial distortions characteristic of the magnetic resonance imaging (MRI) method, which is especially important when assessing the skull base tumors. CT perfusion is a quantitative method, while MRI perfusion is a semiquantitative method, since it uses only relative values.

This study is aimed at assessing the effectiveness of SCT perfusion method as an additional criterion in the differential diagnosis of the skull base tumors.

Material and Methods

In this study, SCT perfusion was performed in 115 patients with tumors of varying histogenesis (Table 1). All patients initially underwent conventional MRI before and after contrast enhancement (T1, T2, T2-FLAIR, DWI).
CT perfusion protocol consisted of three parts. As a first step, low-dose axial CT of the brain with a slice thickness of 5 mm (90 kW) was carried out in order to select the region of interest with allowance for the results of previous contrast enhanced MRI. The perfusion protocol was then carried out according to the prolonged scheme, including two successive continuous scan series. The first part of the protocol includes the dynamic series of CT slices performed every second for 50 seconds [11], followed by an additional series of dynamic slices performed every 20 seconds for the next 3 minutes (a total of 10 series). Highly concentrated solution of the iodide-containing preparation was used as a contrast agent (350—370 mg I/ml, injected into the cubital vein through an automatic injector). A total 40 ml of the contrast agent was injected at the rate of 4 ml/s. Depending on the type of CT scanner (16- or 64-slice system) used for perfusion study, 4 to 8 five millimeter-thick CT slices were obtained. The final stage of the total CT protocol included the post-contrast series of CT images obtained with the spiral scan mode. SCT perfusion was performed with a tube voltage of 80 kV and radiation dose of 200 mAs. The total radiation dose during the whole CT study was 5 to 7 mSv.

The obtained results were processed on a separate workstation (Advantage Window, GE) using Perfusion III software for perfusion data processing. The calculations were performed using the deconvolution algorithm with normalization factor for the velocity of arterial and venous blood flow of 1000 ml/100 g/min. Blood flow values were assessed using 4 cards: blood flow velocity (TBF (tumor blood flow), ml/100 g/min), blood flow volume (TBV (tumor blood volume), ml/100 g), average blood transition time (MTT (mean transition time), s) and microvascular permeability (PS (permeability-surface area product), ml/100 g/min). The regions of interest included the most vascularized tumor areas and intact areas of the white matter of the brain (in some cases, the white and gray matter of the cerebellum, when the tumor was located at the skull base and posterior fossa) as a control. In the intact matter, we usually selected an area located on the opposite side with exclusion of large vessels.

All patients included in the study later underwent surgery or biopsy followed by histological diagnosis.

Statistical analysis of the results was performed using the descriptive statistical methods and correlation analysis (Statistica 8 software package).

### Results and Discussion

The analysis of the results of quantitative measurements of tumor blood flow in 111 patients has shown that the highest values of volume (TBV) and blood flow velocity (TBF) were detected in paragangliomas of the petrous pyramid and juvenile nasopharyngeal angiofibromas compared to other tumor lesions of CSR and skull base region (Fig. 1). These hemodynamic values were several times higher compared to those in the majority of the tumors under study and amounted to 30 ml/100 g, 709 ml/100 g/min, 11, and 250, respectively (Table 2). The lowest values of TBF and TBV were reported in cholesteatomas and chordomas (8.44 ml/100 g/min, 0.89 ml/100 g).

Relatively high values (compared to those in the white matter of the brain) of blood flow velocity (109.25 ml/100 g/min) and blood flow volume (5.89 ml/100 g) were also observed in the largest studied group of patients with meningiomas.

<table>
<thead>
<tr>
<th>Table 1. Distribution of tumors according to their histological type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histological type</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Meningioma</td>
</tr>
<tr>
<td>Pituitary adenoma</td>
</tr>
<tr>
<td>Craniopharyngioma</td>
</tr>
<tr>
<td>Chordoma</td>
</tr>
<tr>
<td>Primary cancer</td>
</tr>
<tr>
<td>Neurinoma</td>
</tr>
<tr>
<td>Angiofibroma</td>
</tr>
<tr>
<td>Metastatic lesions</td>
</tr>
<tr>
<td>Paraganglioma</td>
</tr>
<tr>
<td>Cholesteatoma</td>
</tr>
<tr>
<td>Pilocytic astrocytoma (pilocytic type)</td>
</tr>
<tr>
<td>Esthesioneuroblastoma</td>
</tr>
<tr>
<td>ICA aneurysm</td>
</tr>
<tr>
<td>Cavernous hemangioma</td>
</tr>
<tr>
<td>Neurofibroma</td>
</tr>
<tr>
<td>Plasmacytoma</td>
</tr>
<tr>
<td>B-cell lymphoma</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

![Fig. 1. Juvenile angiofibroma.](image)

Contrast enhanced CT, frontal (a) and axial (b) projections, the color map of the blood flow volume (c). There is homogeneous contrasting of tumor stroma with significant increase in TBF value.
Furthermore, significant increase in the permeability of tumor vessels along with low values of contrast agent transit time (PS=15.54, MTT=4.18) was observed in these cases. Tumors located in the posterior fossa and cavernous sinus were the most common in the group of patients with meningiomas (Table 3).

Histologically, meningothelioma-like structural type of meningioma was the most common one (41 cases). There were also fibroblastic (2), psammomatous (1), and mixed (5) subtypes. There was no statistically significant difference in terms of blood flow in different histological types of meningiomas. Considering the results of MR angiography, the increased hemodynamic parameters were due to a profuse blood supply of meningiomas. The larger blood vessels feeding the tumor and more pronounced vascular matrix of a tumor were associated with the higher velocity and volume of blood flow. The meningiomas of the wings of the sphenoid bone, the medial margin of the petrous pyramid, petroclival region, and the cavernous sinus were characterized by the most profuse blood supply. Convexital meningiomas of the occipital region were the tumors with minimal perfusion.

Our series of observations was characterized by high histological variability of tumors and quite diverse location at the skull base region and CSR, which hindered an adequate comparison of tumors on the basis of sole hemodynamic characteristics (moreover, there was some overlapping of tumors in terms of some perfusion parameters and a small number of cases representing certain histological types). Therefore, we divided the tumors into separate groups depending on the anatomical region and compared them taking into account clinical data and the results of structural neuroimaging.

In cases of tumors located at the projection the sella turcica and parasellar region, the differential diagnosis between pituitary adenomas and craniopharyngiomas (CP) is most often required. The analysis of the blood flow in 8 cases of CP has shown blood flow parameters virtually identical to those in the brain (17 ml/100 g/min) and slightly higher values of blood flow volume (1.5 ml/100 g). The relative prolongation of MTT and increased absolute values of permeability were also observed. Furthermore, SCT perfusion enabled differentiation of CPs according to their histological type as adamantinomallike (6 cases) and papillomatous (2). Thus, the adamantinomallike subgroup of CPs is characterized by low levels of TBF and TBV, while papillomatous CPs demonstrated moderate increase in TBF and high values of TBV. MTT and PS values were similar in both histotypes and were characterized by prolonged time values and increased permeability, respectively.

In the 8 cases with pituitary adenomas, the absolute values of the blood flow velocity in the tumor structure were higher compared to those in CPs. TBV and PS values normalized to the brain (17 ml/100 g/min) and slightly higher values of blood flow volume (1.5 ml/100 g). The relative prolongation of MTT and increased absolute values of permeability were also observed. Furthermore, SCT perfusion enabled differentiation of CPs according to their histological type as adamantinomallike (6 cases) and papillomatous (2). Thus, the adamantinomallike subgroup of CPs is characterized by low levels of TBF and TBV, while papillomatous CPs demonstrated moderate increase in TBF and high values of TBV. MTT and PS values were similar in both histotypes and were characterized by prolonged time values and increased permeability, respectively.

In the cases of atypical growth and unusual radiographic presentation, craniopharyngiomas also had to be differentiated from CSR chordomas, and, more rarely, from primary cancer. The complexity of the differential diagnosis of atypically growing CPs, pituitary adenomas, and chordomas sometimes lies in the similarity of the radiographic semiotics (destruction of bone structures, the presence of petrifications (up to 93% for the CPs [12] and up to 50% for chordomas [13]) and clinical symptoms. The use of SCT perfusion resulted in more objective
and specific process of the differential diagnosis. Low values of all four parameters measured in our study, both absolute and relative (normalized to the brain) is the common characteristic feature of skull base chordomas, regardless of their location, bone destruction magnitude, and the degree of contrast enhancement (see Table 2).

In the cases of tumors located in cavernous sinus, differential diagnosis between meningiomas and neuromas is most often required, and, more rarely, between cavernous hemangiomas and arterial aneurysms of the internal carotid arteries. In adults, meningiomas have the highest incidence and in most cases the correct diagnosis can be established using the standard CT and MRI examinations (the extent of a tumor, contrasting character, the presence of “dural tails”, etc.). In cases of problems with the diagnosis, CT perfusion demonstrated high sensitivity and specificity in diagnostics of these neoplasms (see Fig. 1). According to our data, in 21 patients with meningiomas of the cavernous sinus, the latter were characterized by significant increase in TBF and TBV, and high PS values (Table 2), while in patients with neurinomas, TBF and TBV showed moderate or close to normal brain matter values (TBF=14.45, TBV=1.63 for neurinoma), prolongation of MTT (10.46 s), and increase in PS (5.90). In arterial aneurysms, perfusion values were close to those in the great vessels, while in 2 patients with cavernous hemangiomas, low values of hemodynamic parameters and near-zero PS values were observed.

The routine clinical practice shows that the use of modern capabilities of MRI and SCT in assessment of CSR tumors (mostly extracerebral lesions) in many cases provides rather good visualization of a space-occupying process at the base of the brain, and sometimes even suggests the histological diagnosis of a tumor based on anatomical details. However, this mainly applies to the pituitary tumors and, to a lesser degree, craniopharyngiomas, which are characterized by typical medial location, age differences, and, in most cases, the clinical picture of hormonal dysfunction. At the same time, in some clinical cases, structural and anatomical data obtained using standard MRI and CT protocols, even with intravenous contrast enhancement, are not sufficient to assess the histological structure of a tumor and develop further strategy of treatment. Some tumors, especially large and expanded ones, change the surrounding anatomical structures and acquire new structural properties, which significantly hampers their preoperative differential diagnosis. Moreover, structural neuroimaging techniques do not give the obvious answer to the issues related to such an important aspect as the degree of vascularization of the tumor tissue, necessitating the use of invasive procedures, such as direct intra-arterial angiography. On the contrary, some CSR tumors, even those with small primary size, initially have similar clinical and diagnostic (including anatomical and radiographic) signs. Under these conditions, minimally invasive SCT perfusion study assessing both structural and functional information about hemodynamic changes in the tumor tissue can be considered a method of choice for non-invasive assessment of the histology of pathological processes in the areas inaccessible for both direct surgery and stereotactic biopsy. This method can also be used as an important additional diagnostic marker in the differential diagnosis of tumors and other lesions of the CSR and skull base area.

In our study of the space-occupying masses located at the skull base, the sensitivity and specificity of SCT perfusion were 100 and 81.2%, respectively.

**Conclusions**

SCT perfusion is a minimally invasive, clinically available imaging tool, providing an additional information about the degree of vascularization of the tumor tissue, which makes it a good tool in the differential diagnosis of skull base tumors.

---

**Table 3. Distribution of meningiomas according to their location**

<table>
<thead>
<tr>
<th>Meningioma location</th>
<th>Количество наличий</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior fossa</td>
<td>16</td>
</tr>
<tr>
<td>Cavernous sinus</td>
<td>21</td>
</tr>
<tr>
<td>Skull base</td>
<td>12</td>
</tr>
</tbody>
</table>

---

**Fig. 2.** The color maps of the blood flow velocity: moderate heterogeneous enhancement for neurinoma (a); pronounced enhancement for meningioma (b), and hypoperfusion in the case of chordoma (c).
Conformity with certain hemodynamic criteria and comprehensive assessment of structural and functional information enables preoperative establishing the correct histological diagnosis with a high degree of confidence, making this technique the “in-vivo-histology” procedure. We would like to mention an important role of this technique in assessment of tumors located in the intracranial spatial region, which is hardly accessible for both direct surgery and stereotactic biopsy. Complex application of CT and MRI techniques not only improves the differential diagnosis of tumors, but also provides more reliable evaluation of the treatment, as well as post-operative and post-radiation pathomorphism.

REFERENCES


Commentary

The present article deals with the differential diagnosis of the space-occupying lesions of the skull base. The tumors located in this area represent a heterogeneous group of diseases, which in turn necessitates different approaches to the choice of treatment strategy (surgical resection, radiosurgery, follow-up). In this paper, the authors discuss the effectiveness of the use of CT perfusion method in order to obtain additional information on the histological characteristics of tumors. This method is based on the comprehensive quantitative analysis of the hemodynamic properties of different histological types of tumors. This technique has been used in neuroimaging for a long time. However, most studies focus on the investigation of metabolic changes caused by the acute stroke. In this paper, the authors analyzed 115 cases of patients with sellar and parasellar tumors, who were later treated at the Burdenko Neurosurgical Institute. The method showed high sensitivity (100%) and specificity (81.2%) in the differential diagnosis of tumor located in this area. The capabilities of the method in the differential diagnosis of parangangiomas, meningiomas, neurinomas, and pituitary adenoma were conclusively shown, which undoubtedly affects the choice of subsequent treatment strategy.

In my opinion, the relevance of this work and obtained positive results form the basis for application of this method in routine practice. The article is undoubtedly of great interest to neuroradiologists and neurosurgeons.

M.B. Dolgushin (Moscow, Russia)
Successful Treatment of a Patient with Lhermitte-Duclos Disease (a Case Report and Literature Review)

V.N. SHIMANSKIY, V.V. KARNAUKHOV, L.V. SHISHKINA, E.V. VINOGRAODOV

Burdenko Neurosurgical Institute, Moscow, Russia

**Background.** Lhermitte-Duclos disease is a rare autosomal dominant inherited disease characterized by the loss of the normal cerebellar cortex architecture and the formation of cerebellar hamartoma. The disease usually manifests in the 3rd–4th decade of life. To date, approximately 220 cases of Lhermitte-Duclos disease have been reported in the medical literature. Result. Successful two-stage surgical treatment of a young female patient with Lhermitte-Duclos disease was performed. **Conclusion.** This rare case introduces the clinical presentations and radiographic features of the disease to practitioners, which may facilitate timely diagnosis and proper treatment of the condition.

**Keywords:** Lhermitte-Duclos disease, dysplastic gangliocytoma, inherited disease, PTEN gene, neurosurgical treatment.

Lhermitte-Duclos disease, also known as dysplastic cerebellar gangliocytoma, was first diagnosed by doctors Lhermitte and Duclos in 1920. In subsequent years, the disease was described by many researchers: Bielschowsky and Simons in 1930, Christensen in 1937, Duncan and Snodgrass in 1943, Ambler in 1969, and Padberg in 1991. Each of the authors referred to this disease in a different way: diffuse gangliocytoma of the cerebellum, purkinjeoma, hamartoma, dysplastic gangliocytoma, diffuse ganglioneuroma, and granule cell hypertrophy of the cerebellum. In total, about 220 cases of Lhermitte-Duclos disease have been described in the literature [1].

In 1920, Lhermitte and Duclos described a disease in a 36-year-old male who first developed symptoms of hearing loss on the left and occipital pains at the age of 10 months. Before admission, the patient had paroxysmal vertigo with repeated falls. Examination revealed cerebellar ataxia, dysarthria, nystagmus, and neuropsychic disorders with disorientation and memory impairment. One week after admission, the patient’s condition deteriorated. He was not operated on; the patient’s consciousness level gradually decreased to a coma, and he died.

Considering the disease nature, Lhermitte and Duclos suggested that a pathological lesion found in the posterior cranial fossa during autopsy was a combination of a congenital malformation and a tumor developed from ganglion cells [1, 2].

In 1937, Christensen reported the first successful surgery for dysplastic gangliocytoma of the right cerebellar hemisphere. The surgery was carried out in a 34-year-old male who had suffered the disease since the age of 6 years. The patient had rises in blood pressure, occipital and temporal headaches, nausea, and vomiting at the peak of headache. Sometimes these attacks resulted in the loss of consciousness. The findings at admission included bilateral papilledema, trigeminal nerve impairment on the left, and the right facial paralysis. Ventriculography revealed a displacement of the fourth ventricle and aqueduct to the left. During surgery, a viscous, poorly demarcated, glioma-like mass was found in the right cerebellar hemisphere. The mass was removed, and the patient was discharged without complaints. The patient returned to his work 18 months after surgery. The subsequent course of the disease was not monitored [3].

Now, Lhermitte-Duclos disease is proved to be a hamartoma rather than a tumor [4]. A differential diagnosis of hamartomas and neoplasms is based on preservation of laminated structures of the cerebellum in congenital malformations. Cyst formations, which are usually associated with tumors, are not typical of Lhermitte-Duclos disease. The disease is inherited in an autosomal dominant manner and is caused by a mutation of the phosphatase and tensin homolog (PTEN) gene on chromosome 10q23.31. Approximately 90% of patients with dysplastic cerebellar gangliocytoma have a mutation in this gene or its promoters. The PTEN gene was first identified as a tumor suppressor in glioma. Researchers associated somatic mutations of the gene with glioblastoma, melanoma, and endometrial and prostate cancers. The gene encodes lipid phosphatase for phosphatidylinositol 3-kinase, inhibits serine/threonine kinase formation, alters the phosphatidylinositol 3-kinase pathway, and thereby enhances apoptosis [5–7]. However, despite a large number of studies, the exact etiology andogenesis of Lhermitte-Duclos disease still remain unknown [8, 9].

The disease can be diagnosed at an early age when the first clinical signs of the degenerative pathology in the posterior cranial fossa develop. The duration of symptom manifestation varies from a few months to many years. The largest accumulation of abnormal cells in dysplastic cerebellar gangliocytoma is usually formed by the 3rd–4th decade of life, which is featured in the time course of clinical symptoms [10]. Impairment of the cranial nerves,
Fig. 1. T2-weighted MRI.
Hyperplasia of the right cerebellar hemisphere. Obstructive hydrocephalus.

Fig. 2. SCT angiography.
A dilated occipital vein is seen, which was erroneously identified as an arteriovenous malformation.

Fig. 3. Right-sided cerebral angiography.
Lateral (a) and frontal (b) views. A displacement superiorly and medially to the initial segment of the right posterior cerebral artery and a displacement of the right posterior inferior cerebellar artery behind the midline are observed. Its caudal loop descended into the spinal canal. Wide spreading of the hemispheric branches of the right superior cerebellar arteries is seen.

Fig. 4. Axial view of the brain MRI (T2-weighted mode) demonstrates a patchy pattern of the right cerebellar hemisphere and an increased size of the cerebellum.
IV ventricle is shifted to the left and narrowed. III and lateral ventricles are dilated.
cerebellar ataxia, and clinical manifestations of intracranial hypertension are most often caused by acute or chronic hydrocephalus.

In practice, there are cases of the asymptomatic disease course. In 1969, Ambler described the first familial case of dysplastic cerebellar gangliocytoma observed in a 32-year-old male who died from the disease. Death of his mother was not associated with Lhermitte-Duclos disease. However, conducted investigation revealed that she was a carrier of the asymptomatic disease, which manifested in macrocephaly only. Some members of her family also had a large head circumference; all of them, as emphasized by the author, were asymptomatic carriers of the tumor. Macrocephaly, as one of the additional abnormalities associated with Lhermitte-Duclos disease, occurs in about 50% of cases [2].

Some authors have described this disease in the association with Cowden disease, also known as multiple hamartoma syndrome. Cowden disease is a rare autosomal dominant familial syndrome with a high degree of penetrance and a significant risk for developing breast cancer. Clinically, the disease is characterized by multiple hamartomas. Breast cancer develops in about 30—50% of cases, and thyroid cancer develops in 10% of cases. In 1996, Nelen discovered the Cowden disease gene in chromosome 10q22-23, which partially overlaps with the PTEN locus. This strong tumor suppressor gene was named PTEN/MMAC1. Currently, tumor lesions associated with Cowden disease are proved to occur mainly due to vertical transmission of mutations of this gene [11, 12].

Malformations and a number of other disorders are associated with Lhermitte-Duclos disease to varying degrees. For example, macrocephaly, hydrocephalus, syringomyelia, and skeletal abnormalities (polydactyly, syndactyly, asymmetry of the facial bones) often occur. Lesions, such as lipomas, neurofibromas, hemangiomas, and tongue papules, are less common. Sometimes, Lhermitte-Duclos disease is accompanied by lesions of the

---

**Fig. 5.** MRI of the brain, axial view, T2-weighted mode (2006).

**Fig. 6.** CT of the brain after CSF shunting.

**Fig. 7.** MRI after CSF shunting.

Gangliocytoma of the right hemisphere of the cerebellum with right tonsillar herniation into the foramen magnum, compression, and displacement of adjacent anatomical structures are seen.
thyroid gland, breast, genitourinary system as well as by gastrointestinal disorders.

The main methods of instrumental diagnostics of Lhermitte-Duclos disease include magnetic resonance imaging (MRI) and computed tomography (CT) of the brain [13—17].

Here, we present a clinical case of the disease and its treatment.

A 17-year-old female patient S. was admitted to the Neurological Institute. A few months before admission, she began to note a shaky walk and periodic headache. The neurological status revealed occlusive, cerebral, and pronounced cerebellar symptoms. According to a past medical history, the patient underwent strumectomy for thyroid tumor in 2002 and received L-thyroxine. Since 2006, she was followed-up for macrocephaly. MRI of the brain revealed a space-occupying mass of the right cerebellar hemisphere and obstructive hydrocephalus with periventricular edema signs (Fig. 1). On the basis of CT performed in a vascular regimen, an arteriovenous malformation of the right cerebellar hemisphere was suggested (Fig. 2). To clarify the diagnosis, cerebral angiography was performed that did not confirm the arteriovenous malformation diagnosis (Fig. 3).

Repeated MRI, which the patient underwent at the Neurosurgical Institute, confirmed the previously identified pathology (Fig. 4).

Retrospective analysis of the scans, which had been taken for macrocephaly in 2006, revealed a small space-occupying mass in the right cerebellar hemisphere, which was almost identical to the substance of the cerebellum (Fig. 5).

Thus, it may be concluded that significant growth of the gangliocytoma occurred in the puberty period. The patient underwent ventriculoperitoneal shunting for clinical and radiographic signs of obstructive hydrocephalus with periventricular edema. After resolution of hydrocephalus, the patient retained prolapse of the cerebellar tonsils into the foramen magnum (Fig. 6, 7), which re-

---

**Fig. 8. Ultrasound image of a gangliocytoma during biopsy.**
A hyperechoic lesion with indistinct boundaries is detected.

**Fig. 9. Histological examination of a gangliocytoma.**
a — clusters of atypical hypertrophic ganglion cells (indicated by arrows). Hematoxylin and eosin staining, magnification of 400×; b — immunohistochemical expression of synaptophysin in the cytoplasm and processes of tumor cells, magnification of 400×; c — low MI Ki-67: single labels in nuclei of tumor cells (indicated by the arrow), magnification of 400×.
quired decompression of the craniovertebral junction and a biopsy of the cerebellar lesion (Fig. 8).

Later, we conducted genetic and morphological analysis that confirmed a mutation of the PTEN gene in chromosome 10q23.31. This verified the diagnosis of Lhermitte-Duclos disease and excluded other syndromes.

Microscopic examination of a gangliocytoma reveals a drastic expansion of the internal granular layer of the cerebellum, which contains a plenty of large neurons with vesicular nuclei. These neurons significantly exceed the size of normal cells, but they are a little bit lesser than Purkinje cells. Neurons of gangliocytoma do not divide, but the tumor size can slowly increase due to growth and myelination of neuronal processes (Fig. 9) [5, 18, 19].

During follow-up, the patient had complete regression of cerebellar ataxia and cerebral symptoms. At the time of writing this paper, the patient was followed up by an endocrinologist, geneticist, gynecologist, and a therapist due to a risk of injury to the breast and genitourinary system. The total follow-up period amounted to 5 years. During this period, no gangliocytoma growth was observed. The patient was socially integrated.

Conclusions

Lhermitte-Duclos disease is a rare disease with slow aggravation of symptoms. It manifests mainly in the puberty period or 3rd—4th decade of life. The age range may vary from early childhood to extreme old age. Identification of clinical symptoms and genetic analysis at the early stages of the disease enable timely surgical intervention to increase the quality and length of life of the patient.

The choice of surgical intervention requires a detailed analysis of the clinical and neuroradiological data. The lack of a distinct boundary between a pathological lesion and a healthy cerebellar tissue constitutes a great technical problem for resecting hamartoma. This aspect is confirmed by histopathological examinations that reveal the lack of a transitional area between normal and abnormal cortical tissue [7]. Unlike the normal cerebellar tissue, the pathological lesion has a pale color and is usually located in deep-seated portions of the cerebellum, not on its surface [20, 21]. In this regard, radical surgery is not the best choice because it is associated with a high risk of disability in the patient.

REFERENCES

The article presents a case of successful treatment of a rare genetically determined disease of the cerebellum—Lhermitte-Duclos disease. Despite the fact that the disease was first diagnosed in 1920, about 220 cases of the disease (which is probably a dysgenetic malformation of cerebellar neurons) have been reported in the literature so far. The described case demonstrates the completeness of patient examination using a number of modern neuroradiological techniques as well as genetic analysis, which revealed a constitutional mutation of the PTEN gene, typical of this pathology.

The authors performed staged surgical treatment of the pathology using modern technologies (e.g., neuronavigation). The first stage was ventriculoperitoneal shunting to resolve hydrocephalus, and the second stage included decompression of the craniovertebral junction with autograft plasty of the dura mater and a neoplasm biopsy. The postoperative follow-up period was 5 years. Regression of occlusive, cerebellar, and cerebral symptoms was observed in the patient. No continued growth of the gangliocytoma within the follow-up period was detected. The patient was socially integrated and able to work, which is an important factor because the disease usually occurs during the puberty period or 3rd—4th decade of life. The presented paper will be useful to a wide range of specialists: neurosurgeons, neurologists, endocrinologists, therapists, and urologists.

A. Korshunov (Germany)
Hemostat-induced Granulomatous Inflammation in the Resected Brain Cavernoma Bed in a Child

V.A. KHACHATRYAN, A.V. KIM, K.A. SAMOCHERNYKH, V.S. Sidorin, T.V. SOKOLOVA, O.A. DON, V.P. IVANOV

Polenov Russian Research Neurosurgical Institute, St. Petersburg, Russia

We describe a rare clinical case of productive granulomatous inflammation caused by a gelatin-based hemostatic material in the resected cavernoma bed in the left parietal lobe in a 4-year-old boy. The pathology was detected during follow-up MRI 4 months after the resection. The inflammation was accompanied by the formation of foreign body granulomas; at some sites, the inflammation had the immune nature, with signs of focal destructive vasculitis, delayed maturation of granulation tissue, and disturbance of the organization and encapsulation processes. We also discuss issues of the differential diagnosis and surgical treatment tactics.

Keywords: cerebral cavernoma, cerebral granuloma, productive granulomatous inflammation, hemostatic agent, hemostatic organization, reparative regeneration of surgical wound, pediatric neurosurgery, childhood.

Material and Methods

We describe a rare clinical case of productive granulomatous inflammation in the left parietal lobe of the brain in a 4-year-old child that was induced by application of a hemostat to the resected cavernoma bed. A comprehensive clinical, laboratory, MRI, SCT, US, and pathomorphological examination was performed. Standard histological, cytological, and immunohistochemical techniques were used for analysis of surgical specimens. We used hematoxylin and eosin, May-Grunwald-Giemsa, and Van Gieson staining. Immunohistology was used to determine expression of vimentin in the cytoplasm of mesenchymal cells, a nuclear indicator of the cell proliferation activity (Ki-67), and a marker of neuroglial cells, the glial fibrillary acidic protein (GFAP).

Clinical case

A 4-year-old boy A. suddenly developed tonic-clonic convulsive seizure in the right arm, accompanied by salivation lasting for about 5 min and Todd’s paresis lasting for about 2 h. After 2 weeks, a repeated seizure for about 30 min with speech impairments and Todd’s paresis developed in the association with emotional arousal. MRI examination revealed a space-occupying mass in the left parietal lobe (Fig. 1).

After a standard preoperative examination, the patient underwent craniotomy and resection of a neoplasm, which was histologically identified as a cavernoma. At the end of surgery, a foam gelatin-based hemostat in a combination with thrombin was introduced into the resected cavernoma bed to manage moderate diffuse bleeding from the brain wound edges. The hemostatic effect was achieved. The postoperative period was uneventful, which was confirmed by control SCT (Fig. 2). Blood eosinophilia (up to 11%) and an increased blood sedimentation rate (BSR) (22 mm/h) retained until discharge.

The patient was discharged home in satisfactory condition. Epileptic seizures did not repeat. However, at control examination after 4 months, the boy complained of periodic headaches, and his parents noted easy fatigability, irritability, and sleep disturbance. Right-sided pyramidal insufficiency, more pronounced in the arm, was observed in the neurological status. Ultrasound examination revealed an abnormal lesion of the left parietal lobe, having the isoechic structure, size of 34×37 mm, distinct smooth boundaries, and a 2 mm hyperechoic rim, with no blood flow according to color Doppler. A space-occupying mass of 22×23×21.5 mm in size, with an inhomogeneous MRI signal and annular contrast uptake, was detected at the resected cavernoma site during MRI examination. The
perifocal edema zone was observed (Fig. 3). A blood test revealed $5.8 \times 10^9$ leukocytes per liter, an elevated level of eosinophils (5%), and an increased BSR (23 mm/h).

Given the clinical picture and neuroimaging data, an abscess in the resected cavernoma bed could not be excluded. Repeated craniotomy in the left parietal region and removal of the abnormal lesion were routinely performed. Positive dynamics in the form of regression of cerebral symptoms was observed in the postoperative period. The postoperative wound healed by primary intention. Control MRI scans revealed a residual postoperative cavity, $30 \times 16 \times 29$ mm in size, in the

---

**Fig. 1. Preoperative T1- and T2-weighted MRI scans.**
A cavernoma of the left parietal lobe.

**Fig. 2. SCT, one day after surgery.**
The cavernoma is completely resected; an air bubble is seen in the resected cavernoma bed, which is probably due to application of hemostatic foam.
Fig. 3. MRI of the patient at re-admission.
A space-occupying mass with an inhomogeneous MRI signal and annular contrast uptake is seen in the left parietal lobe, in the resected cavernoma bed. Perifocal edema.

Fig. 4. MRI scans of the postoperative cavity in the left parietal lobe.
No perifocal changes.

Fig. 5. Encapsulated lesion (surgical specimen).
a — general view; b — sectional view. See the explanation in the text.
posteroexternal parts of the left parietal lobe. No perifocal changes were detected (Fig. 4). Before discharge, normalization of blood levels of leucocytes (5.3 • 10⁹ per liter) and eosinophils (1%) was observed, and an increased BSR (32 mm/h) retained.

**Analysis of a surgical specimen**

A surgical specimen macroscopically presented a dense elastic lesion, shaped like a short cylinder of 2.5 × 2.3 × 2.6 cm in size, with a rounding on one of the edges (Fig. 5a). At the center of the lesion section, there was a soft elastic hemostatic mass in the form of a yellow colloidal substance, which had been used to seal the cavity of the previous surgical wound in the brain. This mass was surrounded, without a distinct visible boundary, by a dense light gray connective tissue capsule with a thickness of up to 0.4—0.6 cm (Fig. 5b).

**Histological examination**

At small magnification, histotopograms demonstrate that the hemostatic sealant has a sponge-like structure with irregularly shaped cells filled by a serous fluid, with sporadic weak eosinophilia, which is typical of a protein solution (like blood plasma). The outer layers are represented by a fibrous capsule formed due to maturation of granulation tissue penetrating the cellular colloid mass to different depths in the form of “tongues” with indistinct boundaries (Fig. 6a). Granulation tissue maturation at different sites is very inhomogeneous. There are foci of immature granulation tissue with abundant paravasal leukocytic infiltration, which are located directly in the transitional area between the brain tissue and the colloidal mass filled the surgical wound (Fig. 6b).

The hemostatic substance exhibits intense eosinophilia and fuchsinophilia, which corresponds to its protein, gelatin chemical basis and makes it clearly distinguishable in conventional histological specimens. Closer examination demonstrates that the organization process inside the colloid occurs in the form of productive granulomatous inflammation with the formation of a foreign body granuloma (Fig. 7a). In the inflammation area, active resorption of the colloidal hemostatic mass by macrophagocytes with involvement of giant multinucleated cells and replacement of the hemostat by newly formed soft fibrous collagen masses occur (Fig. 7b). The expression of vimentin is clearly seen in the cytoplasm of most cells of granulation tissue (endothelium of thin-walled vessels, pericytes and fibroblasts, and macrophagocytes, including giant multinucleated cells) (Fig. 7c). Vimentin provides adaptive structural and functional organization of the cytoskeleton in these cells. In this case, actively proliferating cells form sporadic foci, mainly perivasally and, to a lesser degree, in the

---

**Fig. 6. Histotopographic sections (hematoxylin and eosin stain).**

a — granulation tissue invades the colloid and matures to form a fibrous capsule in the upper layers. ×25; b — immature granulation tissue in the transitional area between brain tissue (at the top) and colloidal hemostatic masses (at the bottom). ×50.
endothelium and cells of a surrounding lympho-macrophagic infiltrate. The latter is also confirmed by identification of single Ki-67 positive nuclei in some giant multinucleated cells, which also indicates the formation mechanism of these cells through incomplete cell division — nuclear division without final cytokinesis (Fig. 7d).

In some areas of granulation tissue, the productive phase of inflammation was less pronounced, and exudation with formation of abundant paravascular leukocytic infiltrates was prevalent. In some areas, clusters of eosinophilic leukocytes and plasmocytes were observed (Fig. 8a), which is known to be indicative of the immune nature of inflammation [3]. In the tissue lymph drainage pathways, newly formed primary nodules (lymph follicles) were detected, with some of them having the signs of transformation into secondary nodules with emerging germinal centers (Fig. 8b). They contained a marked concentration of cells with nuclear expression of the Ki-67 protein, which is a proliferative activity marker (Fig. 8c). These nodules in granulation tissue have not been described for healing of ordinary wounds, but their formation basically fits the concept of granulation tissue as a specific temporary effector-receptor peripheral organ of the immune system [4]. Probably, their formation was facilitated by abundant antigenic load accompanying the processes of elimination and of the sealant.

Perivascular leukocytic infiltration foci occurred in deep-seated parts of hemostatic sealant organization. In
some areas, infiltration was accompanied by microfocal purulent destruction of newly formed granulation tissue and by sequestration of hemostatic colloidal microfragments. Perifocal purulent destructive vasculitis was observed (Fig. 9a). In the upper granulation tissue layers corresponding to these inflammation foci, phenomena of delayed maturation of granulation tissue with edema, abundant focal leukocytic infiltration, and signs of purulent destructive vasculitis were observed (Fig. 9b). The signs of perifocal purulent vasculitis also occurred in the adjacent brain tissue where manifestations of edema and reactive gliosis with astrocytic gemistocytosis were particularly noticeable (Fig. 9c). No microbes were found in the colloidal substance of the sealant and destructive inflammatory foci, which gave reason to relate these changes to the manifestations of immune inflammation in the form of the rejection response.

The phenomena of edema and gliosis of the adjacent brain tissue were found in all studied sites. The most pronounced manifestations of gliosis included thickening of the glial fibrous matrix and an increased number and hypertrophy of astrocytes with formation of protoplasmic and gemistocytic elements. Also, porosity of the matrix was observed. A special feature was diffuse and focal clusters of oligodendrogliaocytes swelling and taking the form of “drainage cells”, which is a typical sign of severe cerebral edema [2]. A typical appearance of these cells with a round nucleus and a wide rim of an achromatic cytoplasm makes them particularly distinguishable on the background of the common gliosis signs (Fig. 10a).

We noted a significant number of microglia elements with mesenchymal (monocytic) nature. In some areas, they were represented by macrophages and lipophages, which usually form “granular balls” in foci of brain destruction. Cytological specimens were characterized by a wide polymorphism of microglial and astrocytic elements (Fig. 10b), which is an unmistakable sign of reactive genesis of the described pathological changes [1, 20].

The reactive nature of these changes also manifested in a moderate increase in the cell proliferation activity. This activity was more pronounced around vessels in the mesenchymal stroma, although it was also noticeable among glial elements forming the glial fibrillary matrix of nervous tissue (Fig. 10c). However, glia elements...
Fig. 9. Signs of focal suppurative destructive inflammation of granulation tissue and perifocal vasculitis (hematoxylin and eosin stain).

a — microfoci of purulent destruction of newly formed granulation tissue, ×100; b — immature granulation tissue with edema, abundant focal leukocytic infiltration, and signs of destructive purulent vasculitis, ×100; c — perifocal destructive purulent vasculitis in the adjacent brain tissue. Also, signs of interstitial edema and reactive gliosis with astrocytic gemistocytosis are seen.

remained within boundaries of the surgical wound edge, were not included in granulation tissue, and were not noticeably involved in organization of the material used to seal the wound chamber. This is clearly demonstrated by an immunohistochemical reaction with the glial fibrillary acidic protein (GFAP). Separate microfragments of brain tissue in the wound boundary, being immured in the mesenchymal layer of granulation tissue, were subjected to sequestration, necrosis, cytolysis, and elimination, like a foreign material of the wound sealant (Fig. 10d).

Discussion

Cerebral granulomas are very rare abnormal lesions. To date, the literature [6, 7, 13—16, 19] has reported foreign body granulomas induced by a hemostatic material used in intracranial surgery.

Chemical hemostats have been used in neurosurgery for over 50 years. These include agents based on microfibrillar collagen, oxidized regenerated cellulose, oxidized cellulose, and absorbable porcine gelatin. Absorbable porcine gelatin was used in our case. All these agents are used directly in the area of active bleeding to facilitate its rapid arrest. Fragments of a liquid hemostatic material remain in the surgical intervention field, even after irrigation for the removal purpose recommended by some manufacturers. Therefore, since the introduction of these hemostatic agents, there have appeared publications [6, 7, 13—17] on complications, most of which are represented by infectious-inflammatory responses, hypersensitivity reactions, and granuloma formation associated with failure of hemostat resorption.

It is very important to emphasize that in the present case, the mesenchymal and glial components of reactive changes in the edge of the surgical wound sealed by a hemostat were within a typical pathological process of incomplete reparative regeneration. This manifested in the predominance of the productive phase of inflammation with encapsulation and organization of the colloidal substance of the hemostat. The hemostat was eliminated by macrophagocytes, followed by the formation of foreign body giant cell granulomas and by replacement of granulation tissue. Maturation of granulation tissue toward the wound surface was accompanied by marked accumulation of collagen fibers, which led to sclerosis and formation of the fibrous layer of the pseudocapsule. At some sites, inflammation had the immune nature with signs of rejection of the foreign colloidal material of the wound sealant, which was accompanied by phenomena of focal destructive vasculitis and delayed maturation of granulation tissue with disturbance of the organization and encapsulation processes. This partly explains the clinical picture features.
Fig. 10. Reactive glial changes.

a — signs of gliosis with astrocytosis and gemistocytosis, thickened glial fibrillary matrix and its porosity and clusters of “drainage cells” with achromatic cytoplasm and round central nucleus. Hematoxylin and eosin stain. ×200; b — fibrillary, protoplasmic, and gemistocytic astrocytes are located among microglial cells on the background of blood cells. Cytological specimen — tissue imprint. May-Grunwald-Giemsa stain. ×400; c — nuclear immunohistochemical expression of Ki-67; d — cytoplasmic expression of GFAP in neuroglia elements at the boundary with mesodermal granulation tissue. ×200. See the explanations in the text.

that served the basis for reoperation. Currently, it is not possible to confidently determine whether these effects are mainly associated with the features of the patient’s immune status or antigenic properties of the used hemostatic material.

Granulomatous inflammation around a hemostatic material in the brain has no specific introspective features. MRI scans reveal signs of a space-occupying mass with peripheral contrast uptake that mimics a tumor or abscess [10, 11], which is also confirmed in our case. If the patient was previously operated on for a brain tumor, tumor regrowth cannot be excluded. In this regard, according to S. Jang et al. [5], the use of perfusion MRI and spectroscopy is informative because they enable exclusion of a malignant blastomatous process, which, together with the data of disease history, may help diagnose granuloma. In our case, it was a non-blastomatous disease, cavernoma, whose recurrence after complete resection is unlikely; therefore, a granuloma was suggested before the surgery.

Removal of these granulomas in the absence of brain irritation (paroxysmal symptoms) seems to be reasonable if there are signs of the lesion’s mass effect or lesion infection.

Conclusion

Clinical aspects of diagnostics of productive inflammation around a hemostatic material in the surgical wound are most important in neurosurgical
REFERENCES


The article presents a very interesting clinical case of productive granulomatous inflammation in the resected cavernous malformation bed. In fact, the development of a granulomatous process after application of various hemostatic materials subjected, to varying degrees, to resorption in the surgical wound is not rare. There is a relatively recently adopted term “textiloma” to refer to inflammatory processes associated with the use of hemostatic materials (Diagnostic pathology. Neuropathology. Eds. Burger PC and Scheithauer BW, 2012).

However, the present work is original in that it provides a detailed description of clinically significant manifestations of a cerebral granuloma detected in a child 4 months after resection of a vascular malformation, which required re-operation that had a successful outcome.

Most of the article and illustrations are devoted to a detailed description of the morphological picture of pathology and the applied histochemical and immunohistochemical techniques with determining Vim, GFAP, and Ki-67 expression. The authors demonstrated the predominance of the productive phase of inflammation and organization of a hemostatic material with the formation of giant cell foreign body granulomas, successive stages of maturation of granulation tissue with the development of sclerosis and formation of a fibrous pseudocapsule on the lesion periphery as well as reactive changes in brain tissue. Furthermore, the article indicates the presence of cellular signs for the immune nature of inflammation with the formation of lymphatic follicles. The absence of bacteria in the lesion gave reason to interpret the changes as immune inflammation in the form of a rejection response, which is certainly acceptable and logical. Today, however, a more convincing demonstration of the immune response severity could be application of a wider panel of antibodies using macrophage and lymphocyte markers of T- and B-lymphocytes, which would undoubtedly grace the morphological part of the work.

In general, the article is extremely helpful as a reminder of the possibility of these complications and the ways of developing the treatment tactics and is extremely interesting for neurosurgeons, radiologists, and morphologists.

L.V. Shishkina (Moscow, Russia)
Orbitozygomatic Approaches to the Skull Base

V.A. CHEREKAEV,1 D.A. GOL’BIN,1 A.I. BELOV,1 N.S. RADCHENKOV,1 N.V. LASUNIN,1 A.G. VINOKUROV2

1Burdenko Neurosurgical Institute, Moscow, Russia; 2Federal Clinical Research Center of the Federal Medical Biological Agency of Russia, Moscow, Russia

The article is written in the lecture format and dedicated to one of the major basal approaches, the orbitozygomatic approach, which has been widely used in skull base surgery for several decades. The authors describe the major historical milestones in the development of this approach and its technical features and also analyze the published data on application of the approach in surgery of skull base tumors and cerebral aneurysms.

Keywords: orbitozygomatic approach, skull base surgery.

Definition of the concept and history of the orbitozygomatic approach development

The orbitozygomatic approach (OZA), along with the pterional approach, is one of the most versatile anterolateral approaches to the skull base. The terms “unilateral transbasal” and “orbitozygomatic infratemporal” are synonyms of the term “orbitozygomatic”. Currently, orbitozygomatic approaches comprise a group of surgical approaches to the skull base that suggest involvement of elements of the orbital walls (superior and lateral) and zygomatic bone into the bone block formed during osteotomy. The OZA, which has integrated several limited basal approaches (pterional, supraorbital, zygomatic), is a combined anterolateral approach that perfectly matches the conceptual principle of skull base surgery — to minimize brain retraction. Like any other approach to the skull base, the OZA provides a wide view, short distance to the target region, direct approach, and opportunity to work at various angles, with injury to and retraction of critical neurovascular structures being minimal [1].

The history of surgical approaches to the skull base, which are associated with osteotomy of the orbital walls and zygomatic bone, began in the late XIX century. Resection of the outer orbital wall and zygomatic bone was pioneered by Czermak in 1894, then Gangolphe and Rollet (1901) and Kocher (1907) suggested their techniques.

In 1967, a Bulgarian neurosurgeon L. Karagezov [2] described a new transcranial approach to the orbit, which was also convenient for accessing intracranial mediobasal structures. In this case, an osteoplastic flap included a large part of the superior and outer walls of the orbit. However, the approach was technically complicated and did not gain wide recognition.

In 1982, J. Jane et al. [3] proposed a successful modification of the crano-orbital approach based on studies by L. McArthur and C. Frazier [4, 5], which was called a supraorbital approach. This method was widely used, and its various modifications were developed, in which the flap included the temporal bone, zygomatic bone, and zygomatic arch (supraorbital–pterional, orbitozygomatic, midline supraorbital) [6—10]. In 1984, P. Pellerin et al. [11] described a two-stage orbito–frontozygomatic surgical approach to hyperostotic sphenoid wing meningiomas and reconstruction of the skull base with an autologous bone (cortex of the ilium). Using the technique of P. Pellerin, A. Hakuba et al. [12] developed in 1986 a new surgical approach — the orbitozygomatic–infratemporal approach that widely opened the orbit and base of the anterior and middle cranial fossae. We would say that this is the most versatile approach to extended tumors of the base of the anterior, middle, and posterior (superior parts) cranial fossae.

Two OZA modifications were used: a one-piece approach by K. Ikeda et al. [13] (single fronto–temporo-orbito–zygomatic bone flap) and a two-piece approach, in which convexity craniotomy was first performed, followed by the formation of an orbitozygomatic bone flap. Further practice has demonstrated that the second modification is more preferable (see below).

In 1993, I. Janecka and L. Sekhar [14] described two combined craniofacial approaches: anterior and anterolateral. The anterolateral craniofacial approach was performed through bicornoral and facial incisions, according to Weber–Fergusson. They cut a frontotemporal bone flap and then a facial flap, the size of the latter depended on the tumor spread.

In 1996, Y. Taguchi et al. [15] improved the double-flap cranio–orbital approach by eliminating the risk of postoperative enophthalmos through preserving the lateral orbital wall integrity.

In 1998, J. zabramski et al. [16] presented a large study (83 cases) on the use of their own OZA modification, in which the bone block was separated with a minimal bone loss, which enabled full restoration of the facial skeleton contours at the end of surgery. Currently, two classic OZA modifications are used: the one-piece OZA

e-mail: TCH@nsi.ru
(a bone flap includes the zygomatic process of the frontal bone, frontal process of the zygomatic bone, 1/2 or 1/3 of the zygomatic bone body, temporal process of the zygomatic bone, and zygomatic process of the temporal bone) and the two-piece OZA (an orbitozygomatic bone flap is supplemented by pterional and frontotemporal craniotomy). The two-piece OZA provides a better view of the basal portions of the frontal lobe and reduces the risk of enophthalmos and cosmetic defects [17].

Surgical technique

Here, we provide a description of the OZA technique with allowance for the modern principles of cranial base surgery [2, 18—20].

The patient is in the supine position, with the head rotated contralaterally 45—60° and slightly tilted.

A skin incision starts at the zygomatic arch level, 1 cm anterior to the tragus, and extends superiorly along the coronal suture, departing at least 2 cm from the hairline (Fig. 1 and 2). This incision placement obviates injury to the main trunk of the superficial temporal artery. A skin-aponeurotic flap is separated from the periosteum and temporal fascia, not reaching 2.5 cm to the frontozygomatic suture in order to preserve the frontal branch of the facial nerve located in interfascial tissue. At the superior temporal line level, a myofascial “cuff” is formed by two parallel incisions. The first incision dissects the periosteum above the superior temporal line, and the second incision dissects the temporal fascia below the superior temporal line. Both incisions are joined anteriorly, not reaching 2.5 cm to the frontozygomatic suture. Further dissection is performed subperiosteally and subfascially (see below).

The periosteum is additionally dissected medially, from the posterior edge of the existing incision along the skin incision, forming a “triangular”, brow ridge-based flap. The squama of the frontal bone is elevated to the superior orbital rim using a rasp or oscillating saw. The temporal fascia, muscle (totally or its inner layer) in the form of advanced pedicle flaps can be used for reconstruction of a skull base defect at the end of surgery. If formation of a large defect is initially planned, it is advisable to use a bicoronal skin incision to form a large flap of the calvarial periosteum with a feeding base on the supraorbital ridge side where the flap receives blood supply from the supraorbital and supratrochlear arteries. The next stage is dissection of the temporal muscle (Fig. 3). Like the temporal fascia, the muscle is dissected vertically and horizontally and elevated from the temporal fossa subperiosteally using a rasp to preserve the intraperiosteal branches of the deep temporal arteries irrigating the muscle. This reduces the risk of postoperative atrophy of the temporal muscle, which manifests as a pronounced cosmetic defect. The temporal muscle is separated from the temporal bone squama, greater wing of the sphenoid bone, and posterior surface of the zygomatic bone as inferiorly as possible, after which the muscle is stitched and pulled laterally.

The periorbita is gently elevated from the superior and outer walls of the orbit to the depth of 2—3 cm. OZA osteotomy is performed with a burr or oscillating saw in three stages (Fig. 4):

The periosteal flap, temporal fascia, and temporal muscle (totally or its inner layer) in the form of advanced pedicle flaps can be used for reconstruction of a skull base defect at the end of surgery. If formation of a large defect is initially planned, it is advisable to use a bicoronal skin incision to form a large flap of the calvarial periosteum with a feeding base on the supraorbital ridge side where the flap receives blood supply from the supraorbital and supratrochlear arteries.

The next stage is dissection of the temporal muscle (Fig. 3). Like the temporal fascia, the muscle is dissected vertically and horizontally and elevated from the temporal fossa subperiosteally using a rasp to preserve the intraperiosteal branches of the deep temporal arteries irrigating the muscle. This reduces the risk of postoperative atrophy of the temporal muscle, which manifests as a pronounced cosmetic defect. The temporal muscle is separated from the temporal bone squama, greater wing of the sphenoid bone, and posterior surface of the zygomatic bone as inferiorly as possible, after which the muscle is stitched and pulled laterally.

The periorbita is gently elevated from the superior and outer walls of the orbit to the depth of 2—3 cm. OZA osteotomy is performed with a burr or oscillating saw in three stages (Fig. 4):

Fig. 1. Topography of anatomical landmarks of the calvarium and temporal and zygomatic regions with regard to the orbitozygomatic approach.

1 — coronal suture; 2 — superior temporal line; 3 — superficial temporal artery; 4 and 5 — frontal and parietal branches of the superficial temporal artery; 6 — frontal branch of the facial nerve; 7 — supraorbital neurovascular bundle; 8 — frontozygomatic suture; 9 — posterior margin of the frontal process of the zygomatic bone; 10 — zygomatic arch.
The remaining fixation of the orbitozygomatic bone flap to the zygomatic and sphenoid bones is coped by careful lifting of the flap, starting with the zygomatic bone body side; after this, the flap is completely mobilized. The flap is pulled down on the masseter muscle, opening access to the infratemporal fossa.

The order of the two-piece OZA stages is obvious: craniotomy should come before cutting the orbitozygomatic bone flap. This provides greater preservation of the superior and outer walls of the orbit, which thereby are included in the orbitozygomatic flap. This provides better functional and cosmetic outcomes in the postoperative period.

Pterional craniotomy, if it is required, is carried out in accordance with the standard principles covered in manuals on neurosurgical techniques.

Further stages of the surgery should be performed under optical zooming, preferably under control of an operating microscope.

The dura mater is separated from the sphenoid crest and sphenoid wings to the anterior inclined process, superior orbital fissure, the round, oval, and sphenotic foramina, and petrous pyramid, if necessary. The periorbita is elevated from its walls to the superior and
inferior orbital fissures; then, retractors are placed on the periorbita and dura mater to ensure safe osteotomy. The remaining medial part of the sphenoid crest is resected to expose the superior orbital fissure. The lateral and superior margins of the superior orbital fissure are removed by a burr. In our practice, we prefer minimal resection of the orbital roof to prevent postoperative pulsating enophthalmos.

The optic canal is opened extradurally using fine bone forceps to expose the optic nerve sheath. To expose the clinoid segment of the internal carotid artery, the anterior clinoid process, along with its root, is cut using a small spherical burr with diamond coating, under irrigation. These manipulations facilitate mobilization of the internal carotid artery and optic nerve after opening the dura mater and simplify surgical manipulations in the anterior and middle cranial fossae, parasellar area, and interpeduncular cistern. The anterior clinoid process is cut from inside to the thin bone plate that is easily removed using forceps.

Resection of the inferolateral parts of the greater wing of the sphenoid bone enables wide exposure of the inferior orbital fissure and round foramen located in the fissure projection, with the oval foramen being visualized behind the round foramen. Extradural dissection enables exposure of the middle meningeal artery, which enters the cranial cavity through the spinous foramen. Further dissection exposes the greater petrosal nerve posteriorly to the oval foramen; injury to the nerve can cause ipsilateral anhidrosis. The greater petrosal nerve is transected in rare cases when access to the petrosal segment of the internal carotid artery is required.

In our view, electrophysiological monitoring should be used to preserve the superior orbital fissure nerves of the cavernous sinus; this reduces the rate of complications associated with dysfunction of the oculomotor muscles [21].

The choice of the extradural or intradural approach is based on the features of the tumor location and spread. Once the surgical manipulations are completed, tight suturing the dura mater is performed. Dura defects can be closed by a free flap of the calvarial periosteum. In the case of a large dura defect in the area of the superior orbital fissure and anterior parts of the cavernous sinus, which is often observed in meningiomas of the medial portions of the sphenoid wings, it is advisable to use combined reconstruction using a periosteal flap and advanced pedicled buccal flap (this reconstruction technique is described in detail and illustrated in our publications) with fixation of the plasty material by sutures and adhesive compositions [22, 23]. The orbitozygomatic (and pterional, in the case of a two-piece OZA) flap is placed back and fixed with titanium miniplates and screws or nonabsorbable sutures. If a substantial deficit of bone tissue of the orbital walls, especially the orbital roof, is observed during replacement of bone flaps, reconstruction of bone defects is recommended for prevention of pulsating exophthalmos.

The temporal muscle is placed in its bed and sutured with single sutures to the myofascial “cuff” and to the posterior transected part of the muscle. The temporal fascia is sutured in the same way in a separate layer. The aponeurosis and skin are sutured in two layers.

The standard practice is placing a U-shaped (mattress) suture on the eyelids and a moderately compressing bandage on the eyeball to prevent aggravation of orbital tissue edema and chemosis. It is very important to moisten the conjunctiva because the lack of moistening in the presence of chemosis may cause cicatricial changes [20]. Therefore, starting the first postoperative day, the patient should be daily examined by an ophthalmologist for toilet of the conjunctival cavity. Sutures are removed from the eyelids and a compressing bandage is canceled on the 5th postoperative day in the absence of eyelid edema and chemosis. An ice bag or cold compresses can be used to prevent periorbital edema.

Fig. 4. Osteotomy lines.
1 — zygomatic process of the frontal bone; 2 — fronto-zygomatic suture; 3 — frontal process of the zygomatic bone; 4 — body of the zygomatic bone; 5 — temporal process of the zygomatic bone; 6 — temporozygomatic suture; 7 — zygomatic process of the temporal bone; a — osteotomy of the zygomatic bone body, b — osteotomy of the zygomatic process of the temporal bone. Perioral craniotomy is denoted in green.
Advantages of the orbitozygomatic approach in surgery of skull base tumors and circle of Willis aneurysms

The OZA has been extensively used in neurosurgery and has been reasonably considered the “work horse” of skull base surgery [24, 25]. The OZA, which is in fact an extension of the ptoral approach [24], surpasses it due to removal of a flap comprising the superior and lateral orbital walls and zygomatic arch as well as retraction of the temporal muscle and contents of the orbit to increasing the angle of view. These differences are of key importance for expanding the surgical corridor and reducing retraction of the frontal and temporal lobes [20, 26, 27]. Special measurements demonstrated that the differences in angles of the operating action in the ptoral and orbitozygomatic approaches are significant. According to A. Nanda et al. [28], the anteroposterior angle was 56±5° with the OZA versus 48±6° with the ptoral approach (p<0.01), while the rostrocaudal angle was 61±9° versus 51±9° (p<0.05), respectively. An increased amount of bone resection when using the OZA instead of the ptoral approach transforms a narrow space into a wide corridor, enabling the surgeon to work closer to the target without additional retraction of the brain. According to the evaluation by L. Gonzalez et al. [29], the difference in the angle of vertical visibility is 10.2±0.7°; when the orbitozygomatic flap includes a maxilla fragment (maxillary expansion), extra 4.8±0.6° is added. These data are consistent with the results of our measurements: compared to the ptoral approach, the angle of surgical view with the OZA increases by 27° (84%) in the frontal plane and 19° (60%) in the horizontal plane.

In a study by E. Figueiredo et al. [30], the vertical and horizontal angles of the approach were larger for the OZA than for the ptoral approach. Since the vertical approach angle is limited by retraction of the frontal lobe, it is statistically significantly larger in the OZA. The value of the angle of horizontal visibility in the OZA was also statistically significantly larger than that in the ptoral approach. In a study by V. Filipce et al. [31], in microscopic exposure, the greatest working area (204.5±33.9 mm2) was provided by the OZA as compared to the supraorbital (114.8±26 mm2) and ptoral (170±20.4 mm2) (p<0.05) approaches.

A number of authors [20] argue that it is sufficient to complement ptoral craniotomy by mobilization of the zygomatic arch. But in this modification, the temporal muscle restricts the vertical angle of visibility; therefore, the ideal solution is osteotomy of the entire zygomatic bone, like in the OZA, which provides withdrawal of the temporal muscle beyond the surgical corridor.

The OZA has been actively used for skull base tumors and vascular pathology [27]. The approach provides a wide view of the anterior and middle cranial fossae, area of the basilar artery apex and superior parts of the clivus, infratemporal and pterygopalatine fossae, apex of the petrous pyramid, and tentorial notch region [1, 20, 26—28, 32]. The indications for using the OZA include aneurysms of the anterior cerebral and anterior communicating arteries, sphenoïd wing meningiomas, basilar bifurcation aneurysms, craniopharyngiomes, pituitary adenomas, chordomas, parasellar meningiomas, and Meckel’s cavity tumors (meningiomas, neuromas) [20].

The OZA is convenient for resecting trigeminal nerve aneurysms located in the middle and posterior cranial fossae, which cause erosion of the apex of the petrous pyramid. However, a large size of the tumor site in the posterior fossa prevents complete tumor resection using the approach [26].

The OZA increases visibility of the medial portions of the temporal lobe and has advantages over the traditional subtemporal approaches because it provides a convenient and minimally traumatic approach to the internal carotid artery branches (anterior choroid, posterior cerebral, and posterior communicating arteries), minimizes retraction of the temporal lobe and the risk of injury to the vein of Labbe, and avoids transcortical manipulations or lobectomy having the risk for language and memory functions [33].

In neurovascular surgery, the OZA has been recognized as one of the approaches to the anterior parts of the circle of Willis and basilar artery apex. The credit for popularizing the OZA in surgery of cerebrovascular aneurysms is due to M. Yasargil [29].

The advantage of OZA is improved visibility of the A1—A2 segments of the anterior cerebral artery and anterior communicating artery along the vertical and horizontal axes without the need for resection of the straight gyrus [30, 31]. According to M. Kinoshita et al. [34], the OZA is the only approach that enables visualization of these structures without significant retraction of the brain.

The basilar artery apex area is one of the most complex and hard-to-reach areas on the inferior cerebral surface. In this respect, it is necessary to note advantages of endoscopic assistance that provides excellent visibility of the basilar artery bifurcation without the need for dissection of the lateral wall of the cavernous sinus, which simplifies access to this anatomical area [28].

Postoperative results and outcomes were the object of several studies that compared the OZA with ptoral and others approaches to the anterior and posterior parts of the skull base. The literature data are quite contradictory. For example, according to A. Nanda et al. [28], the OZA is a more traumatic approach and increases the surgery duration. G. Lernote et al. [27] argue that this extended approach increases postoperative morbidity compared to that of the ptoral approach. At the same time, A. Yousef et al. [25] demonstrate that the OZA neither significantly increases postoperative morbidity nor leads to poor cosmetic outcomes. According to W. van Furth et al. [20], the cosmetic outcome in the case of
a properly performed OZA is the same as in the pterional approach, and ptoisis may persist after surgery for several weeks, but usually completely regresses. Only 2 of 250 patients had partial ptosis for longer than 6 months.

A. Youssef et al. [25] analyzed a series of 75 patients operated on for various craniobasal lesions using the OZA and reported the following data on complications: ocular movement restriction (2.4%), cranial nerve deficit (8.5%), liquorreha (1.2%), pseudomeningocele (2.4%), and intracerebral hemorrhage (1.2%). No one of the patients had partial ptosis for longer than 6 months. Only 2 of 250 patients had partial ptosis for longer than 6 months.

It should be noted that postoperative complications were more frequently associated with tumors than with vascular pathology. 78.5% of patients were satisfied with the cosmetic outcome of surgery.

**Conclusion**

The OZA is one of the basic approaches in skull base surgery because of its obvious advantages and executability. A statistically significant increase in the angle of attack, the possibility of extending the surgical field, and no need for retraction of the frontal and temporal lobes are the indisputable advantages of this approach that make it indispensable in a number of situations. It should be noted that modern neurosurgery gives preference to the two-piece OZA because this surgical technique minimizes resection of the bone walls of the orbit because of their inclusion in the orbitozygomatic flap, which is not technically possible in the case of a single fronto-temporo-orbito-zygomatic flap.

**REFERENCES**

doi: 10.1097/01.CNS.000038404a9.
doi: 10.1227/01. NEU.0000093134.83201.06.

32. Gol'bin DA. Endoscopic assistance in surgery of tumors with the craniofacial spread: Candidate of Medicine Thesis. Moscow 2010. Available at: http://www.dissercat.com/content/endoskopi-cheskaya-assistentsiya-v-khirurgii-opukholei-kraniofatsialnogo-rasprostraneniya. In Russian. Link was active on 03.20.15.


Topics to be covered in our next issue

● ‘Virtual consultation’ in neurosurgery

● Epidemiology of spinal tumors

● Pseudomeningocele with spinal cord compression